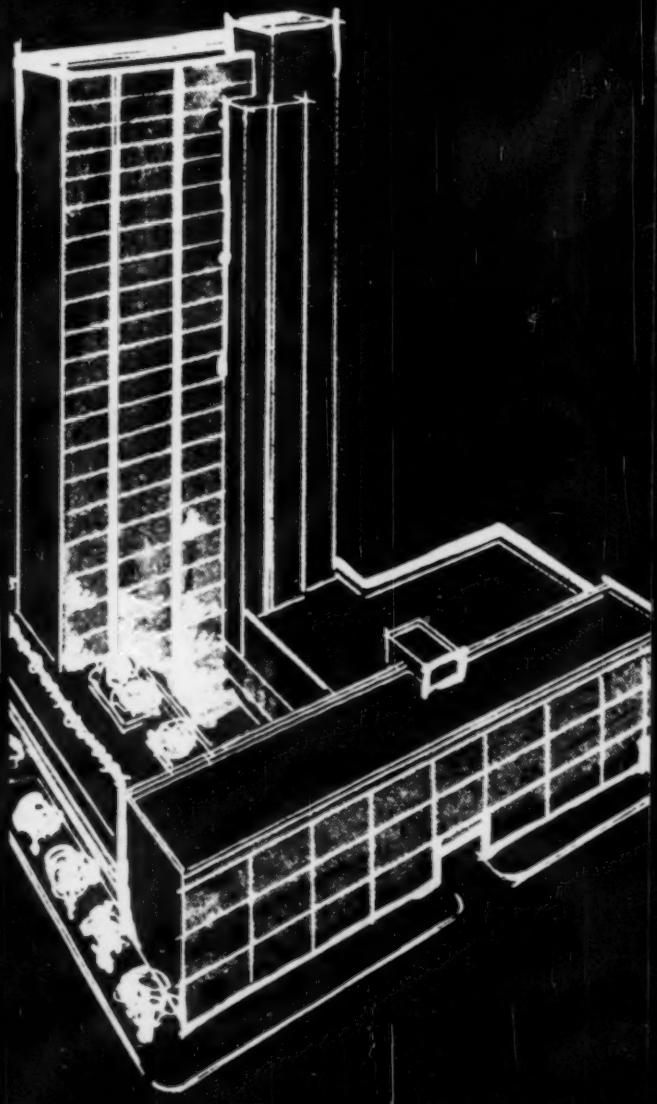
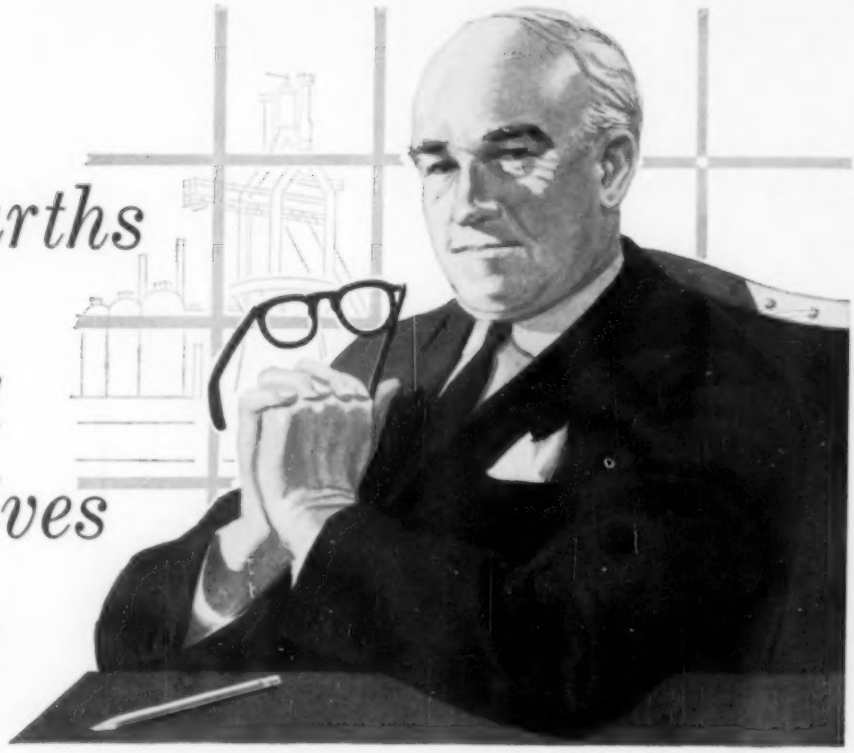
JOURNAL OF

METALS

FEBRUARY 1958



Rare Earths and Steel Executives



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JOURNAL OF

METALS

VOL. 10, NO. 2 FEBRUARY 1958

Published to provide a continuing, authoritative, and up-to-date record of technological, engineering, and economic progress in all branches of the industry by The Metallurgical Society, American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., 29 West 39th Street, New York 18, N. Y.

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COVER

As different as day from night is how Cover Designer Naomi Lazard chooses to characterize four-hundred years of progress in metallurgy. On the left of this month's cover is a woodcut from Agricola's *De Re Metallica*, showing conditions in the sixteenth century, and on the right is a view of the United Engineering Center, which will be the twentieth century home of the AIME, along with other national engineering societies. For latest news on the new center, turn to page 83.

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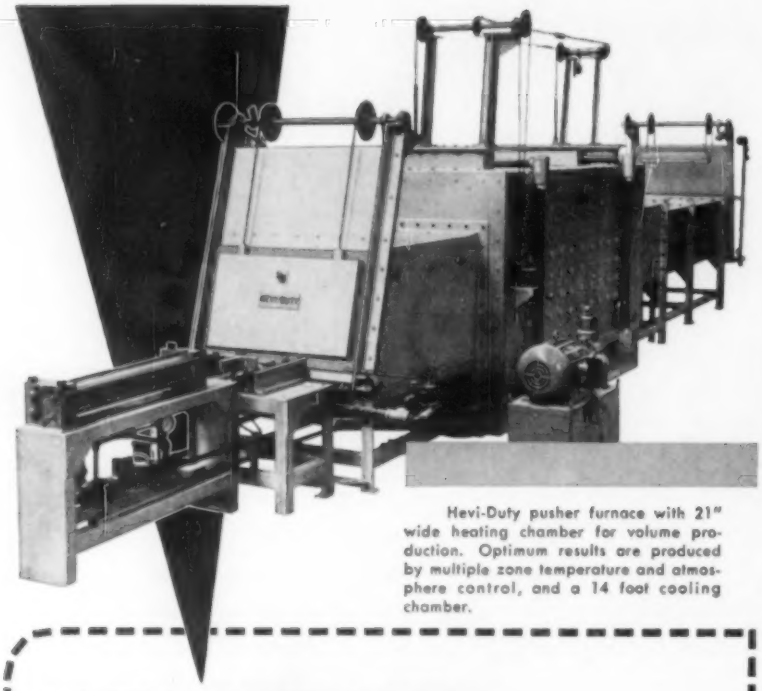
Published the first day of each month by the American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 29 West 39th Street, New York 18, N. Y. Telephone: PEnnsylvania 6-9220. Subscription $8 per year for non-AIME members in United States and North, South, and Central America; $10, foreign; $6 for AIME members, or $4 additional for members only in combination with a subscription to "Mining Engineering" or "Journal of Petroleum Technology." Single copies, 75 cents; single copies foreign, $1.00; special issues, $1.50 . . . The AIME is not responsible for any statement made or opinion expressed in its publications . . . Copyright 1958 by the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. . . . Registered cable address, AIME New York . . . Indexed in Engineering Index, Industrial Arts Index, and Chemical Abstracts . . . Second class mail privileges authorized at New York, N. Y., and additional entry established at Manchester, N. H. Number of copies in this issue 10,700.



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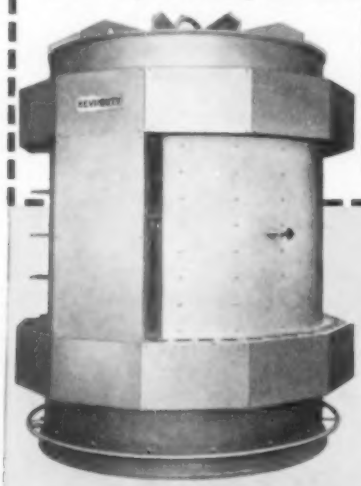

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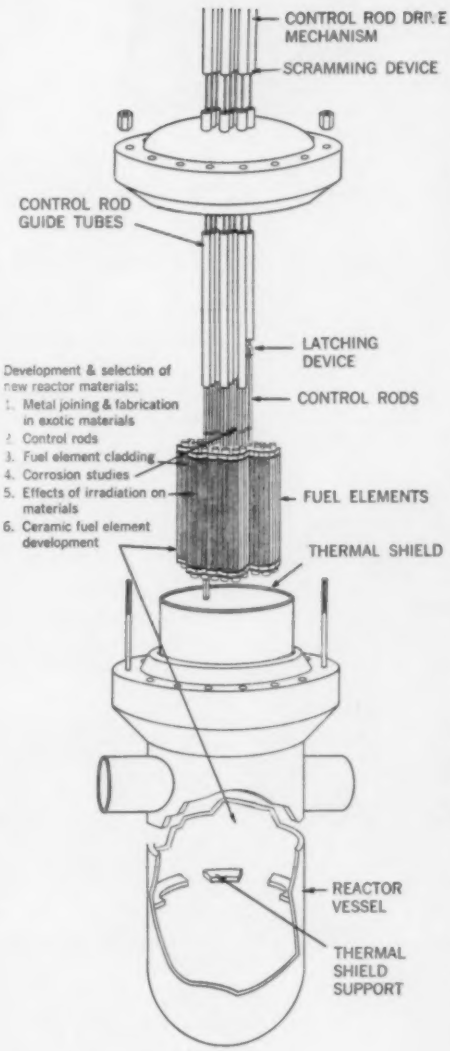

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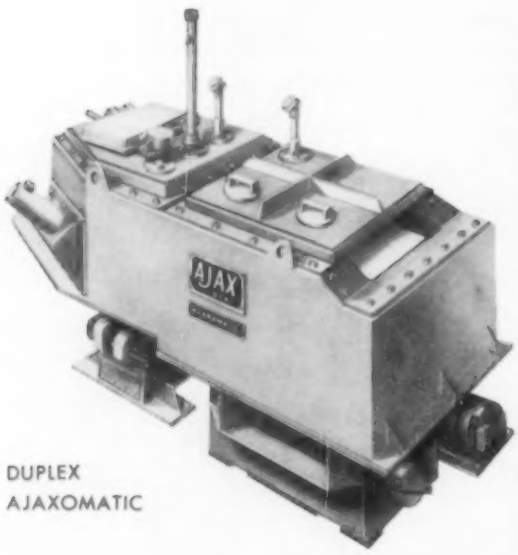

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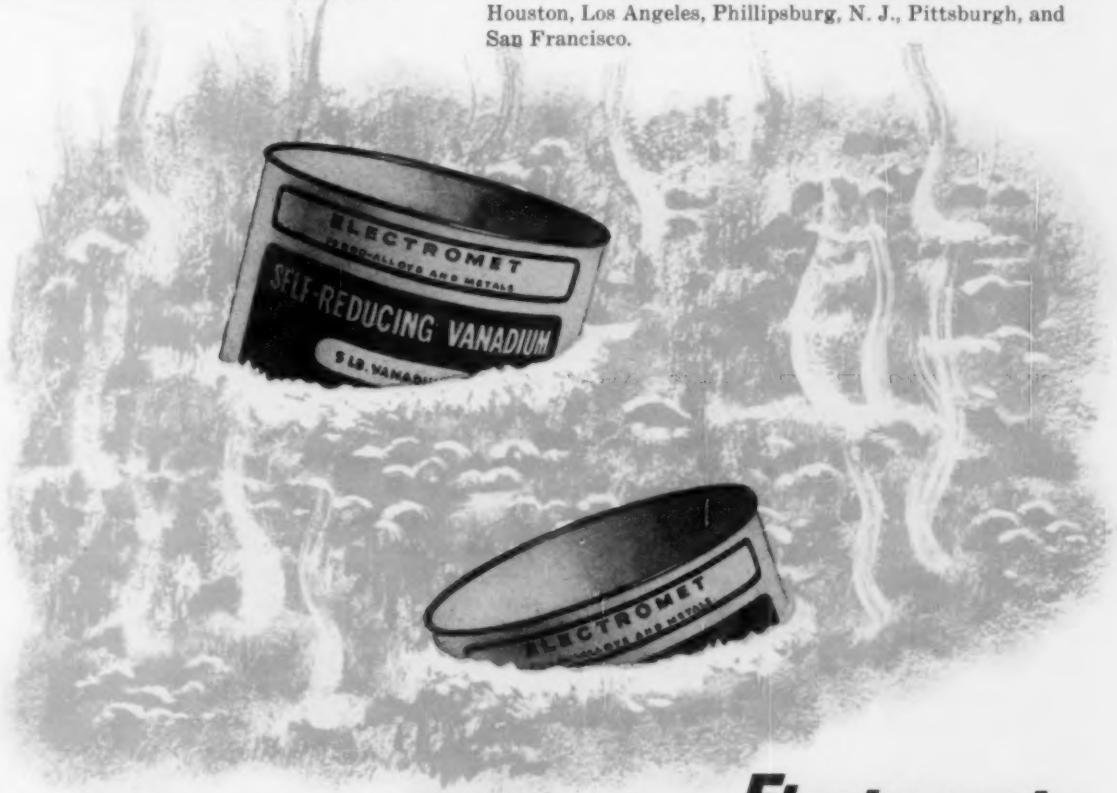

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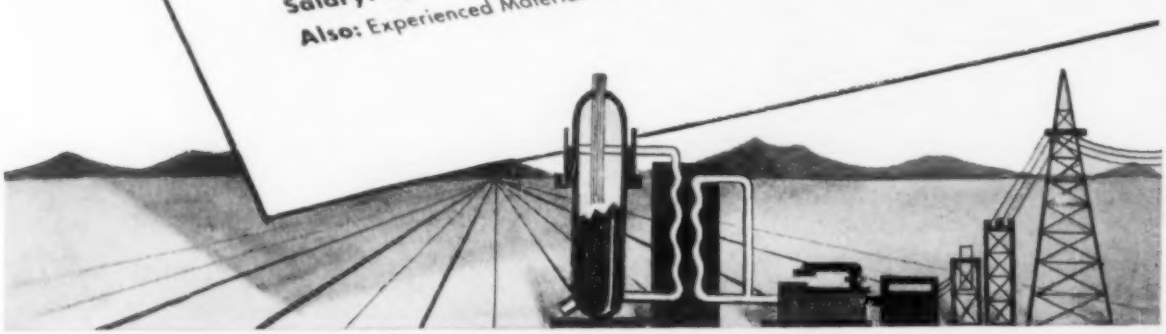

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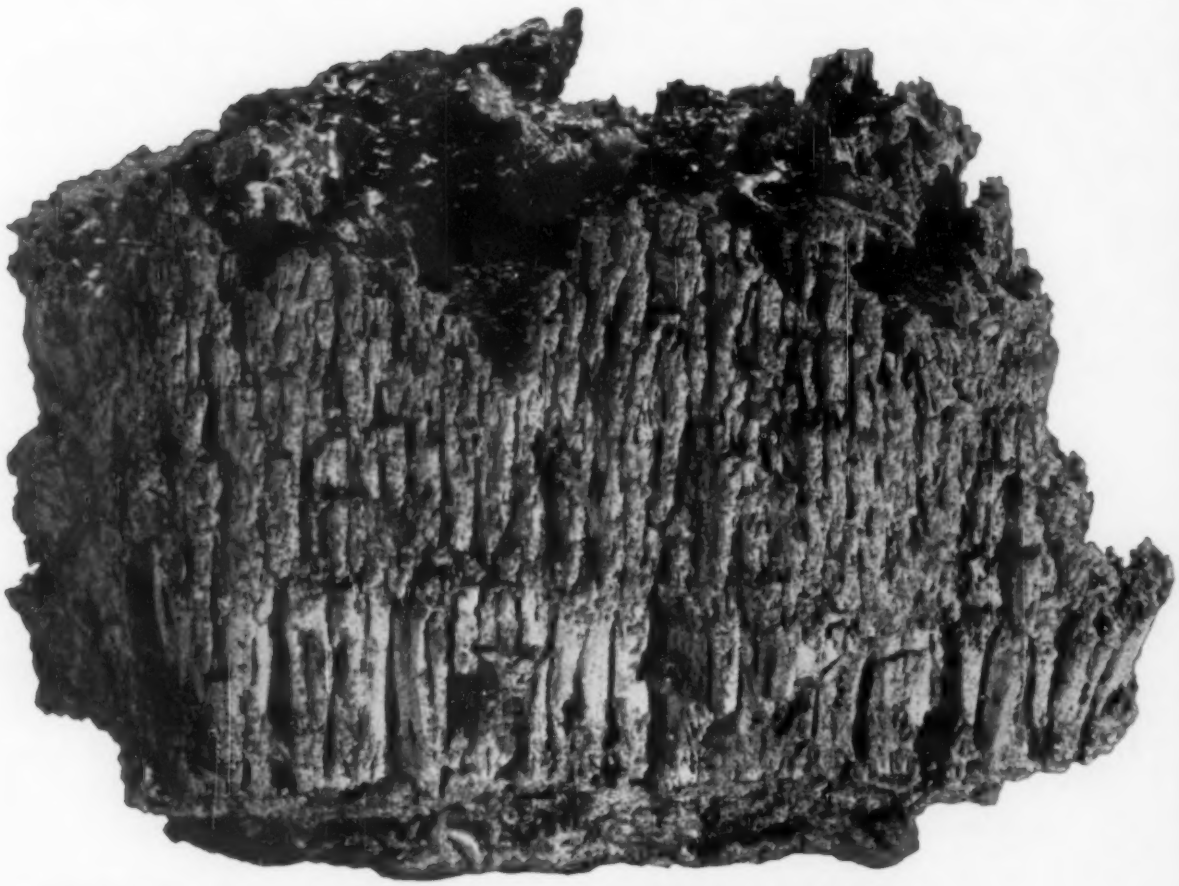

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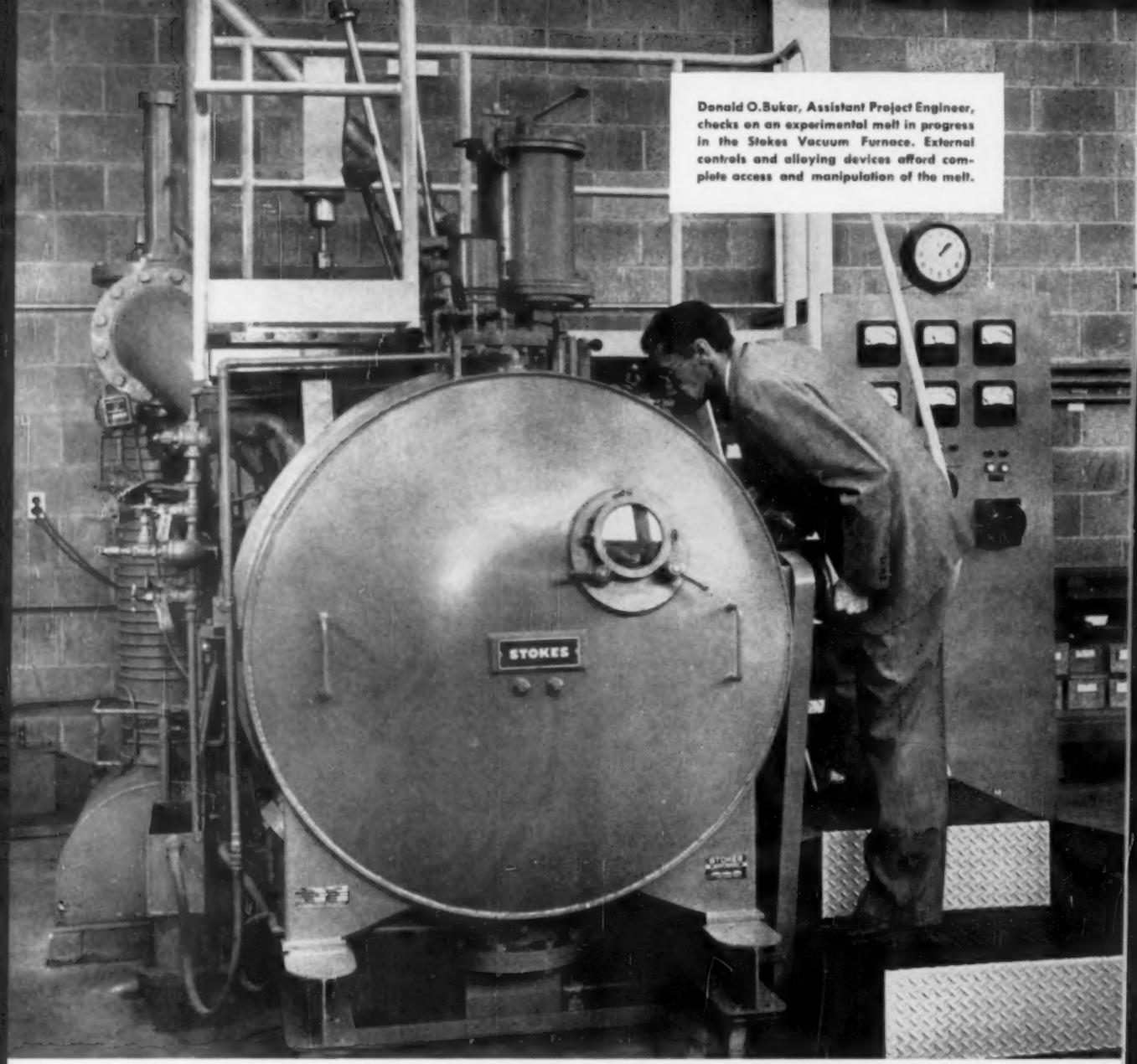
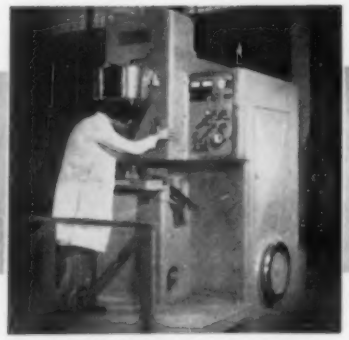
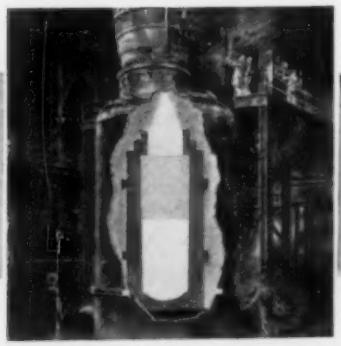


Donald O. Buker, Assistant Project Engineer, checks on an experimental melt in progress in the Stokes Vacuum Furnace. External controls and alloying devices afford complete access and manipulation of the melt.

THE METALS INDUSTRY IS PROFITING FROM THE USE OF OTHER STOKES PRODUCTION EQUIPMENT



Powder Metal Presses. Cost savings and the compacting of incompatible alloys have made powder metallurgy an accepted process. Stokes offers the most complete line of presses in the industry.



Stream Degassing Systems. Stokes offers production equipment which can control hydrogen content of steel to less than 1 ppm by removing the gaseous impurities from the molten metal.

Vanadium Corporation of America keeps Stokes Vacuum Furnace busy in Ferroalloy Research

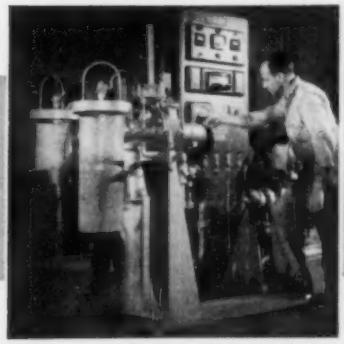
A Stokes Vacuum Furnace System, installed in the Cambridge, Ohio Research Center of Vanadium Corporation of America is kept constantly on the go . . . exploring new ideas that someday may be applied to production procedures for ferroalloys and master alloys. Investigations include the degassing of alloys produced by commercial production practices, and the melting of metals too reactive to be satisfactorily processed in normal atmosphere.

For example, various vanadium-containing alloys have been remelted . . . to determine property improvement and extent of gas removal under specified temperature and pressure conditions. Another use involves the melting of higher titanium-content alloys which would oxidize excessively in air. The research center is also concerned with alloys containing boron, calcium, lithium, chromium, magnesium, columbium and tungsten.

T. W. Merrill, Director of Product Research, advises "we have found that the furnace performs very satisfactorily, and has met all our expectations in this regard."

Stokes Vacuum Furnaces are extremely flexible, ruggedly built units, designed for developmental or production runs . . . in sizes ranging from 17 lb. to greater than 5,000 lb. melts. Production units are fully engineered with charging and mold vacuum locks for semi-continuous operations. In all these units, a broad selection of accessories and features is available. Of particular interest is the fact that, as in the case of Vanadium, Stokes easily makes special customer accommodations to meet individual requirements.

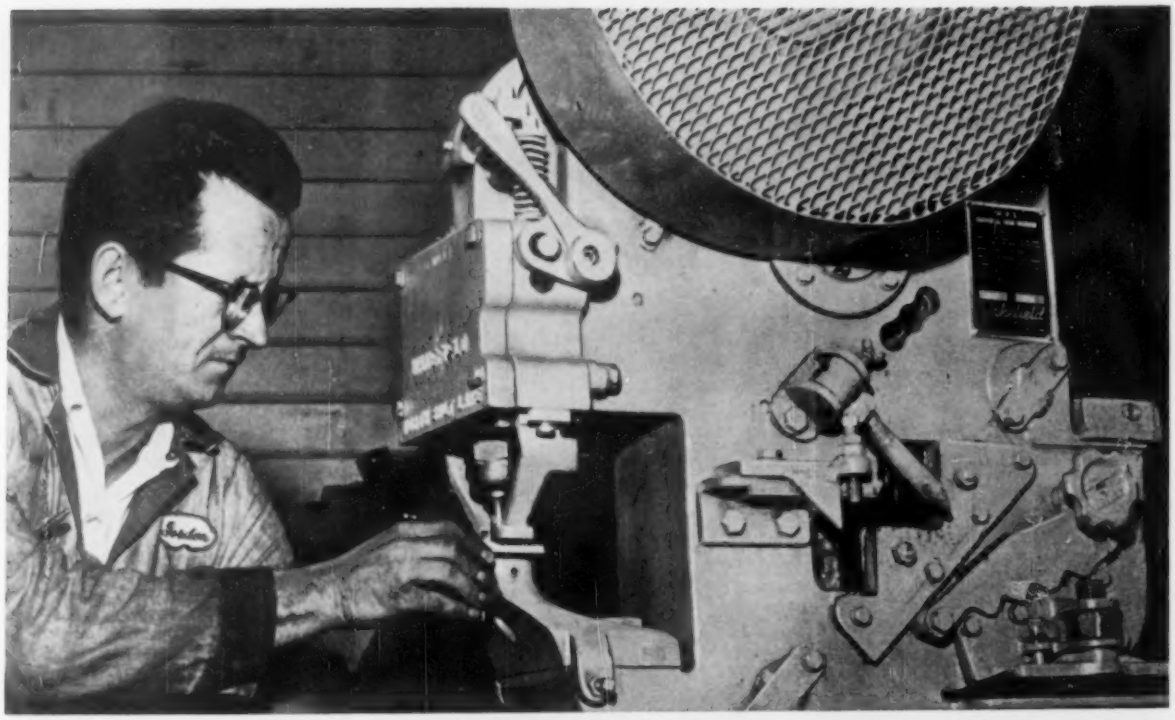
Complete technical information and specifications are available on Stokes Vacuum Furnaces and accessories. For detailed application engineering, the Stokes Advisory Service is available for consultation and recommendations concerning your exact requirements. Write today.

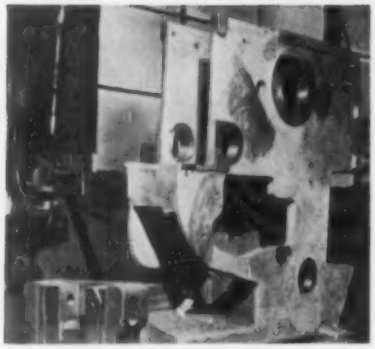


Heat Treat Furnaces. Compact Stokes vacuum furnaces are available for many commercial heat treating applications. Sequenced and centralized controls afford utmost convenience in handling of work and cycles.

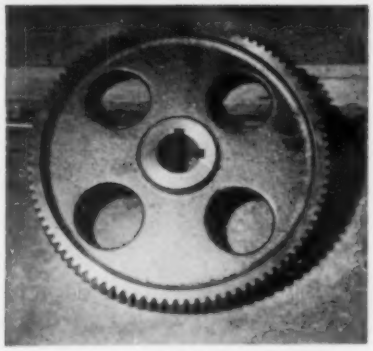
Vacuum Equipment Division
F. J. STOKES CORPORATION
5500 Tabor Road, Philadelphia 20, Pa.

STOKES

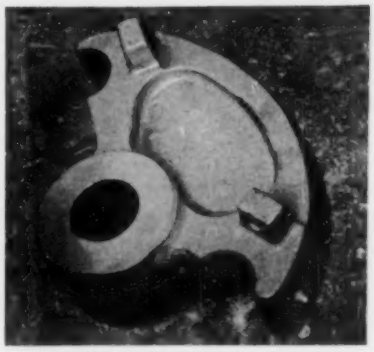




Cast frames with tensiles up to 200,000... eliminate flame cutting of rolled sheet steel.



Cast gears that Brinnel to 475... that withstand heavy loading even with ordinary lubricants.



Machine bearing surfaces right in the castings... eliminate bushings, without sacrificing service.

Build machines like this for less money ...the ductile iron way

Wakefield, Inc., of Salt Lake City, Utah, makes 95% of the cast parts for their "Iron Worker" portable mechanical press of ductile iron.

With ductile iron, they benefit two ways. First, they get the *process* economies of cast iron – good castability, machinability, moderate cost. Second, they gain many of the product advantages of steel – tensile strength of 73,000 to 80,000 psi, yield strength of 63,000 to 67,000 psi, good elastic modulus, excellent impact resistance. In addition, they get the excellent wear resistance of cast iron. Castings are supplied by Backman Foundry, licensed producers of ductile iron.

For more information about ductile iron castings, write for new 28-page Inco bulletin, "Ductile Iron Digest."

THE INTERNATIONAL NICKEL CO., INC.
67 Wall Street New York 5, N. Y.

ductile iron...the cast iron that can be twisted and bent.

1957—High Metal Output Despite Declining Rates

1958—Improvements Foreseen in Second Half-Year

. . . Steel in 1957

American steelmaking furnaces logged third highest year on record in 1957, producing 113 million net tons of ingots and castings. Output of the UK and of the European Coal & Steel Community (ECSC) was at record levels, with production at 24.3 and 66 million net tons, respectively. Increase over 1956 was greatest for ECSC—5.3 pct—compared with 4.8 pct for the UK and 4.1 pct for the USSR. ECSC output was achieved despite lower coal output—blamed on manpower shortages—and slackening steel export markets.

. . . Steel in 1958

Roger M. Blough of U. S. Steel Corp. predicts, ". . .steel output in the first half of this year may be little changed from the levels of recent weeks." H. K. Intemann of Electro Metallurgical Co., Div. of Union Carbide Corp. says that 1958 steel output ". . .will probably not exceed 109 million ingot tons", but "Operating rates in the second half of 1958 are expected to be higher than those in the first half."

. . . Copper, Lead, and Zinc in 1957

Production of copper, lead, and zinc from domestic mines decreased about 5 pct from 1956, reflecting lower domestic consumption. On the other hand, foreign mine output increased more, so that world production of all three metals was at peak levels. World copper consumption increased over 1956, while lead and zinc decreased, but in no case was demand sufficient to prevent substantial price declines. Reduction in the US government's stockpile program for lead and zinc in May caused many mines to close or curtail production. Reductions in copper output were substantial, but they were largely offset by new properties or expansion of existing mines.

. . . Copper in 1958

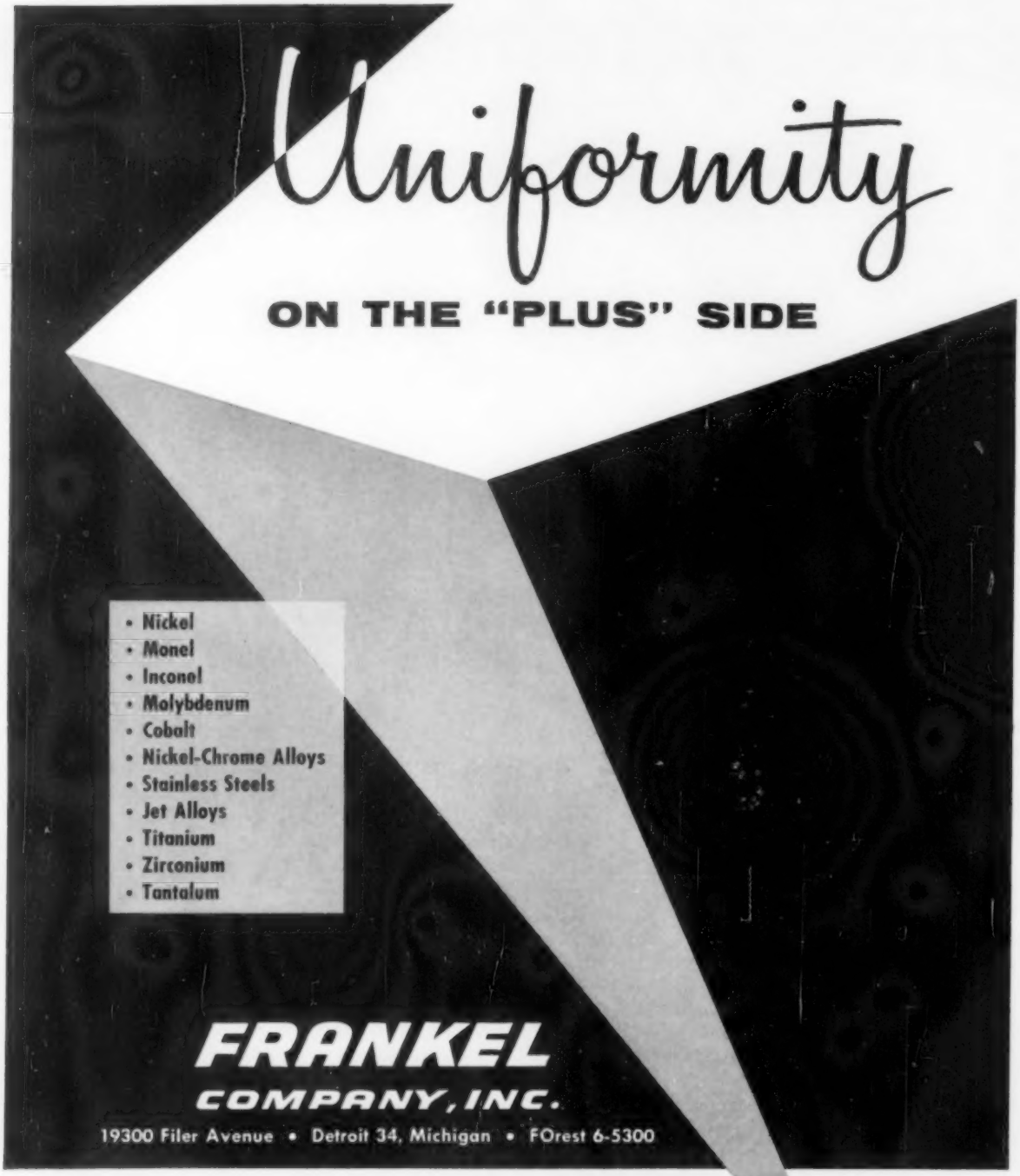
With estimated world copper production still running some 150,000 annual tons ahead of consumption, the copper industry is hopefully looking toward a reversal of the downward trend which many economists expect in the second half of 1958.

. . . Nickel in 1957

John F. Thompson of International Nickel Co. reports, "After many years of nickel shortage for civilian purposes, the . . . supply . . . came into close balance with demand in nearly all areas of the world during the last part of 1957. In fact, in the largest market, the United States, the supply exceeded demand." Continuing, "This change was brought about by a record-high free-world production of nickel, sharply reduced defense demands, and the U.S. government's endeavor to divert to industry during the year all nickel scheduled for stockpile intake." "Free world nickel supplies in 1957 are estimated at 490 million lb, compared with the previous high of approximately 450 million lb in 1956 . . . Deliveries of the metal by the several Canadian producers will reach a new high total of 360 million lb. . ."

. . . Nickel in 1958

Dr. Thompson concluded, ". . it is expected that there will be more nickel available . . . in the coming year than was the case in 1957." "In view of the announcement of the U. S. government that it desires to divert to industry all nickel scheduled for stockpiling, it is expected that the supply in this country will exceed the demand."



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No wonder more and more buyers of secondary special alloys are turning to Frankel.

EDITORIAL

Fund Drive Underway For New Center

THE United Engineering Center, so essential if the Engineering Societies are to pace the growth of the engineering profession in this increasingly technological age, is day by day coming closer to reality. The first phase of the fund drive, the Industrial Campaign, is headed by Mervin J. Kelly, President of Bell Telephone Laboratories, and is now in progress. Among those working with Dr. Kelly is an outstanding group of prominent AIME members, including four past presidents of the Institute: H. DeWitt Smith, Leo F. Reinartz, Carl E. Reistle, Jr., and Donald H. McLaughlin, along with W. B. Stephenson, and Will Mitchell, Jr. Dr. Kelly's committee is charged with raising $5,000,000 toward completion of the $10,000,000 building.

The second phase of the drive, the Member Gifts Campaign, is being handled by the societies themselves, and will begin for the AIME at the Annual Meeting in New York this month. President Grover Holt will address the All-Institute Technical Session, to be held Tuesday, February 18, on the subject, and plans for the drive will also be presented to the Council of Section Delegates. Honorary Chairman of the Member Gifts campaign is Charles F. Kettering, with Joe Gilson heading the AIME drive. The goal is $3,000,000., with the AIME's share set at $500,000.

As was noted in the January JOURNAL OF METALS, the Honorary Chairman of the Building Fund Campaign is Hon. Herbert Hoover, thirty-first President of the United States, and President of the AIME in 1920.

Sponsors of the campaign include many men familiar to the metals and metallurgical research field. The Campaign Executive Committee includes Louis S. Cates, former president of the Institute and Chairman of the Board of Phelps Dodge Corp.; Ralph J. Cordiner, President, General Electric Co.; Morse G. Dial, President, Union Carbide Corp.; Eugene G. Grace, Honorary Chairman of the Board, Bethlehem Steel Co.; and James R. Killian, Jr., President of Massachusetts Institute of Technology, and now Special Assistant to the President for Science and Technology. Among the distinguished scientists and engineers sponsoring the campaign are two former presidents of the Institute, Clyde E. Williams, until recently President of the Battelle Memorial Institute, and John R. Suman, consultant.

Metals men included in the list of sponsors from industry include Roy H. Glover, Chairman of the Board, The Anaconda Co.; Charles R. Hook, Chairman of the Board, Armco Steel Corp.; J. D. Hitch, Jr., President, Dorr-Oliver Inc.; J. R. MacDonald, Chairman of the Board, General Cable Corp.; Joseph L. Block, President, Inland Steel Co.; C. R. Cox, President, Kennecott Copper Corp.; Joseph A. Martino, President, National Lead Co.; C. M. White, Chairman of the Board, Republic Steel Corp.; R. S. Reynolds, Jr., President, Reynolds Metals Co.; Robert E. Wilson, Chairman of the Board, Standard Oil Co. (Indiana); and Roger M. Blough, Chairman of the Board, U. S. Steel Corp.

As financial backing for the new structure comes into being, plans for the building itself are nearing completion, and the list of occupants is taking shape. In addition to the four Founder Societies (ASCE, AIME, ASME, and AIEE) and AIChE, nine other national engineering societies, one local society, and four inter-society groups have expressed interest in occupying the new building. These are as follows:

American Institute of Consulting Engineers
American Rocket Society, Inc.
American Society of Heating & Air Conditioning Engineers, Inc.
American Welding Society
Illuminating Engineering Society
The American Society of Refrigerating Engineers
The American Water Works Association
The Society of Naval Architects and Marine Engineers
The Electrochemical Society, Inc.
Municipal Engineers of the City of New York
American Standards Association
Engineering Index, Inc.
Welding Research Council
Engineers' Council for Professional Development

In addition to the above named groups, three others, the American Institute of Industrial Engineers, Inc., the Society of Motion Picture and Television Engineers, and the Engineers Joint Council, will be eligible provided that they qualify for a tax free status.

Let us all hope that, by our own efforts and the support of industry, at this time next year the United Engineering Center Building Fund Campaign will have been successfully completed and construction will be underway.

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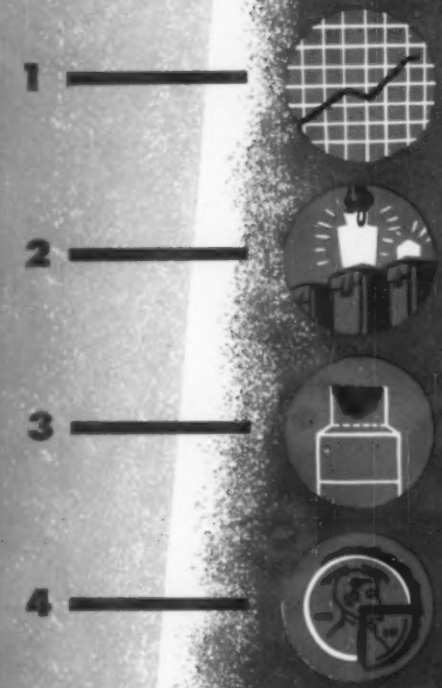
INGOT MOLD WASH



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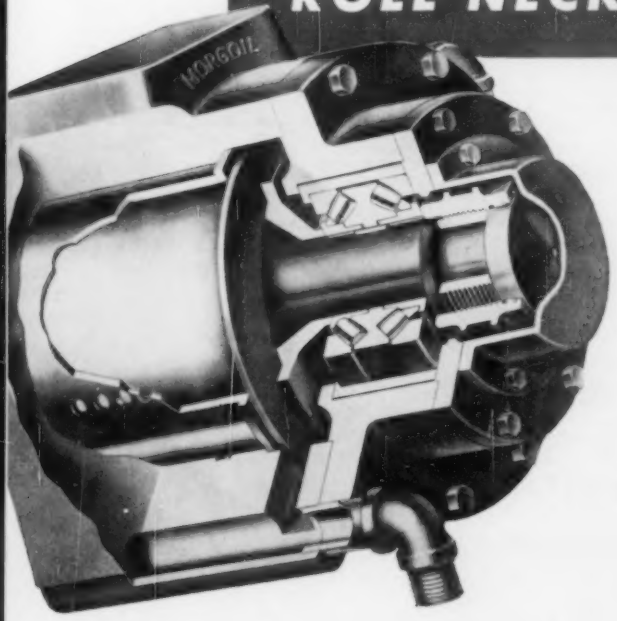

MORGOIL—the bearing that gives the greatest capacity and the longest life regardless of speed—gives modern high speed rolling mills top quality production with minimum down time due to bearing or roll neck failure.

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Top salary for right man.

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Director of Personnel
Alan Wood Steel Co.
Conshohocken, Pa.

METALLURGIST: Responsible position as leader of research group for the study and development of high strength materials for rocket hardware. Location, Western Pennsylvania research institution. Detail education and experience in first letter.

Box 3-JM AIME
29 West 39th St. New York 18

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Ore dressing and extractive metallurgy. Salary depends upon experience. Write to:

Chairman, Department of Mining and Metallurgy, Texas Western College, El Paso, Texas.

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The facilities of the Connecticut Aircraft Nuclear Engine Laboratory of Pratt & Whitney Aircraft are completely new. Research and development equipment is exceptional—both in quantity and quality.

At CANEL you'll find the challenge, the encouragement, and the equipment to help you do your best work and earn the rewards of accomplishment. It will pay you to investigate.

METALLURGISTS

SUPERVISOR, JOINING DEPARTMENT . . . to direct research and development of welding, brazing, cladding, and diffusion-bonding activities. At least six years' experience in allied research and development. Advanced degree desirable but equivalent research experience more essential.

SUPERVISOR, METALLURGICAL DEVELOPMENT . . . to direct alloy development programs. Work will include melting and fabrication and coordination of test evaluation. Ph. D. level desirable. At least six years' experience in similar work will be acceptable with a B. S. degree.

SUPERVISOR, METALLURGICAL RESEARCH . . . to direct research work in metal compounds, diffusion studies, phase equilibria work, and theoretical metallurgy consultation with other laboratory programs. Ph. D. level or equivalent required.

SUPERVISOR, FABRICATION DEVELOPMENT . . . to direct development of duplex structures by extrusion, rolling, or pressing. Cladding studies, development and preparation of cermets. B. S. or M. S. with strong background and at least six years in relevant work required or Ph. D. with two or three years of experience.

METALLURGICAL ENGINEER . . . to do liaison work between design, experimental manufacturing and the laboratories. Duties will include close follow-up of all materials development programs and coordination with shop operations. At least three years' applicable experience with B. S. or M. S. in metallurgical engineering.

METALLOGRAPHER . . . to conduct metallographic investigations of materials and to coordinate with other laboratory activities. Candidates should possess a strong interest and at least three years' experience in metallography as related to x-ray diffraction, phase equilibrium relationships, and properties. B. S. or M. S. degree in metallurgy.

RESEARCH METALLURGIST . . . to assist in metallurgical research programs including alloy development, metal compounds, diffusion studies, and phase diagram studies. Advance degree desirable or B. S. with at least three years' experience in applicable work.

METALLURGISTS . . . recent graduates for work in materials testing, materials development, and non-destructive inspection development.

CHEMISTS

SUPERVISOR, ANALYTICAL CHEMISTRY . . . to direct analytical research and development and to supervise routine analytical work. Problems include analysis of trace elements in metals and gases, liquid metal analysis, advanced techniques using wet chemical methods. At least six years' experience in similar work required. Ph. D. level or equivalent.

RESEARCH CHEMIST, INSTRUMENTAL ANALYSIS . . . to work on development of spectrographic methods, including emission, x-ray fluorescence, and mass spectroscopy. X-ray diffraction experience desirable. At least three years of applicable experience. Advanced degree desirable.

RESEARCH CHEMIST, PHYSICAL CHEMISTRY . . . to assist in high-temperature chemical research and development programs including determination of physical properties and of solubilities. Candidate should possess an advanced degree with at least three years of applicable experience.

CHEMICAL ENGINEERS OR CHEMISTS . . . to assist in development work in analytical chemistry, physical chemistry, or corrosion. Recent graduates.

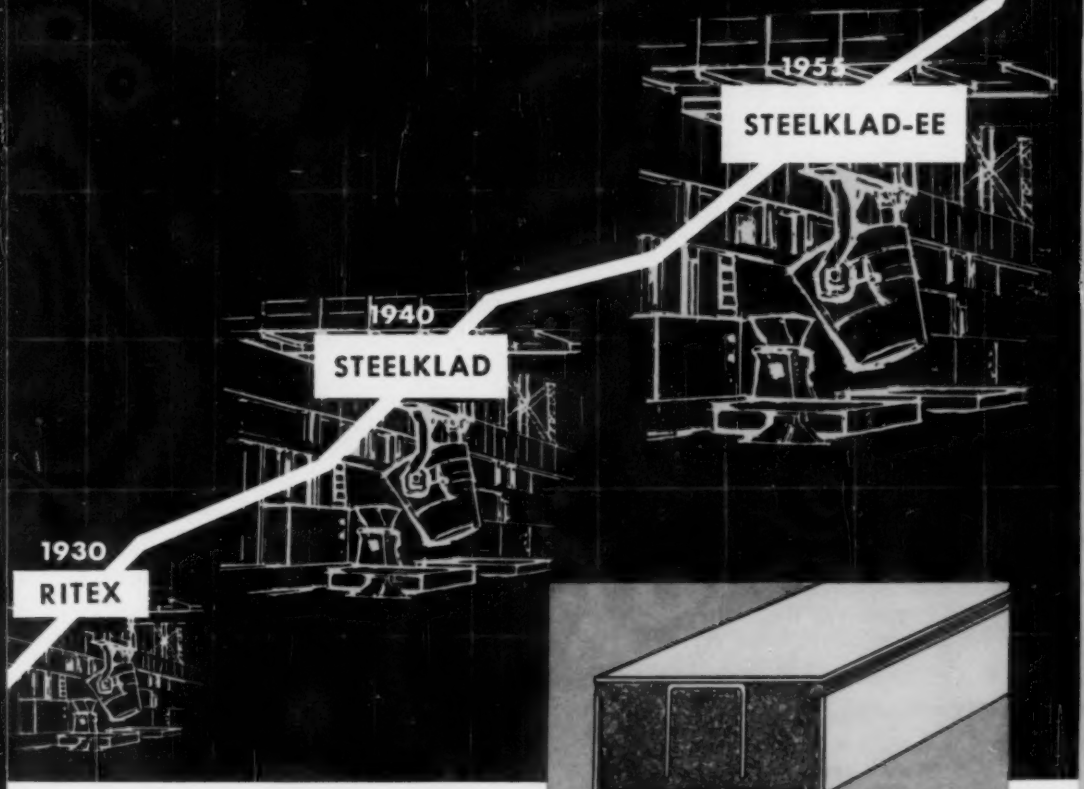
Please send complete resume to Mr. L. T. Shiembob, Office 2, Employment Department.

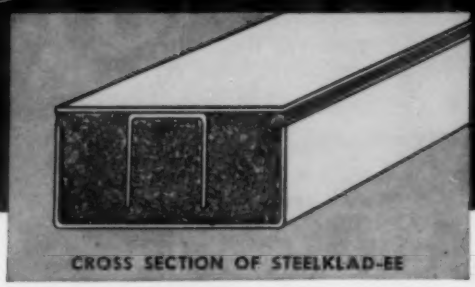
PRATT & WHITNEY AIRCRAFT CANEL

Box 611, Middletown, Conn.

STEELKLAD-EE

The ORIGINAL Internally Plated Brick





CROSS SECTION OF STEELKLAD-EE

Steel production in the U. S. A. has more than doubled in the last quarter century. General Refractories' constant improvement of basic brick for steel making has greatly helped this striking growth.

Early in the period of expansion Grefco pioneered the development of chemically bonded RITEX brick. In the forties Grefco's STEELKLAD provided increased spalling resistance and still better refractory quality. Continuing research and study brought about the introduction three years ago of Grefco's patented STEELKLAD-EE. These brick have now proved themselves in a great many applications. In this short time STEELKLAD-EE has won a substantial and growing portion of the basic brick market. In many applications they have demonstrated increased life of from 25% to 50% over other basic brick.

The cut-away view shows how the STEELKLAD-EE internal plates are molded into the brick, making three bricks of one. These smaller refractory units are tremendously more resistant to the spalling and peeling action which has been characteristic of most basic brick on exposure to cyclical heating and cooling.

For expert advice on the use of this outstanding, new, basic refractory, consult your local Grefco representative.

A Complete Refractories Service

GENERAL REFRACTORIES COMPANY · PHILADELPHIA 2, PA.

GENERAL REFRACTORIES

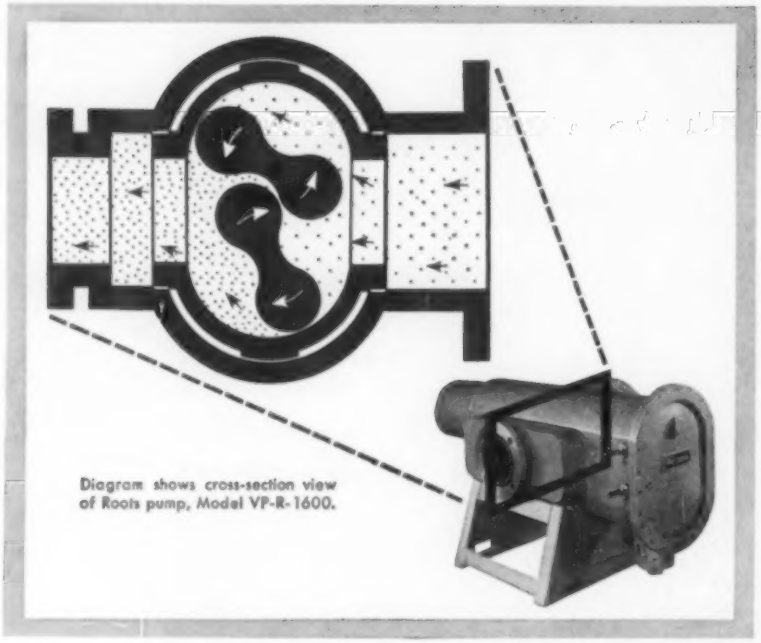


Diagram shows cross-section view of Roots pump, Model VP-R-1600.

How to get vapor-free high vacuum

fast . . . with the ROOTS pump

Now you can achieve completely dry pressure in the 10^{-1} to 10^{-5}mm Hg range using only a *mechanical* high-vacuum pump.

Probably the world's fastest pump in this range, the new Roots pump works without the aid of oil or steam vapors.

A pair of finely machined rotary pistons do the pumping. The pistons never touch one another or the pump casing, so the Roots pump needs no oil sealing. It cannot contaminate a system with backstreaming vapors.

Consider these other advantages:

1. Speed. The model shown above has a throughput of 10,400 micron cu. ft. per minute at 10 microns.

2. No shaft seals, no leaks. Motor operates within the vacuum.

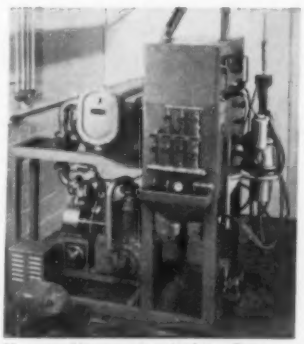
3. No by-pass or valving. Roughing is done directly *through* the pump.

4. Quiet. The Roots pump does not vibrate when in operation.

5. Low power consumption.

Under a license with the manufacturer, Heraeus (Hanau, Germany), CEC is exclusive agent for all seven models of the Roots pump in this country.

For data on performance and theory of operation, write for Bulletin P8-20.



Heraeus Vacuum Arc Melting Furnaces are also available from CEC. Note Roots pump used. Furnace melts "buttons" to ingots. Particularly useful for obtaining pure samples of metals with high melting points. Information in Bulletin P4-28.

Consolidated Electrodynamics

Rochester Division, Rochester 3, N. Y.

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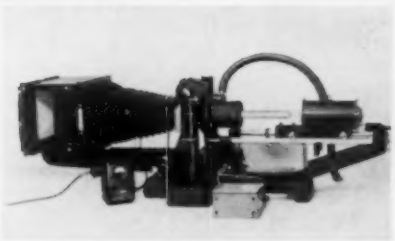
Plastic Tooling Shrinkage Test Method, by Orville D. Lascoe, the *American Soc. of Tool Engineers,* ASTE Research Fund Director, 10700 Puritan Ave., Detroit 38, Mich., 118 pp., $4.00 ASTE Members, $6.00 Nonmembers, 1957.—This fully illustrated report establishes consistent, accurate data of plastic tooling shrinkage research essential to both consumers and producers of plastic materials. The book completes the second step in the extensive plastic tooling research project being conducted by the Purdue Research Foundation under the auspices of the ASTE Research Fund. Included in the report is a summary of the six methods tried and full details of each investigation, an equation developed from statistical theory for predicting shrinkage after known period of time, and a mathematical relationship between volumetric and linear shrinkage for a solid cylinder and a rectangular solid. Purdue's study not only provided two satisfactory methods for measuring shrinkage, but a better understanding of what shrinkage is and how it occurs.

Physics of Nuclear Fission, International Series of Monographs on Nuclear Energy, Div. vol. 2, English translation, *Pergamon Press,* 122 E. 55 St., New York 22, N. Y., $10.00. —This volume brings together in book form the text of a special supplement to the Russian Journal *Atomnaya Energiya.* Containing the papers read at the Conference on the Physics of Nuclear Fission, held at the Atomic Energy Institute of the USSR Academy of Sciences, it provides detailed reviews of the most important problems regarding the physics of nuclear fission. This is a book of vital interest and value to all who need to keep abreast of international progress and development in the field of nuclear energy and fission especially.

Solid State Physics, by Adrianus J. Dekker, *Prentice-Hall Inc.,* $12.00.—This book is a practical and thorough source of self-study written for the physicist, chemist, engineer, or metallurgist interested in the physical properties of solids. The material is so organized, that the book's 20 chapters are to a considerable degree independent of each other and permit the reader to choose his own

(Continued on page 90)

Leitz *for accurate analytic results*



Leitz **DILATOMETER**

for accurate metal analysis

Researchers consider dilatometric analysis the most sensitive and reliable method for precise determination of the expansion coefficient of metals, including the new ultra-high melting point alloys and ceramics. The DILATOMETER records volume changes in relation to its own temperature (absolute curve), yielding data for coefficient expansion determinations.

Leitz **METALLUX** *microscope*

for superior metallography

Superlative optical qualities and outstanding operational features make this Leitz instrument the logical choice in metallurgy: unobstructed upright stage, inclined eyepieces, unique quintuple nosepiece, built-in, vertical illumination. The METALLUX is equipped for phase contrast observations. Accessory equipment adapts the METALLUX for material testing-photography. Low-position controls for fatigue-free observation.

Leitz **SHOP** *microscope*

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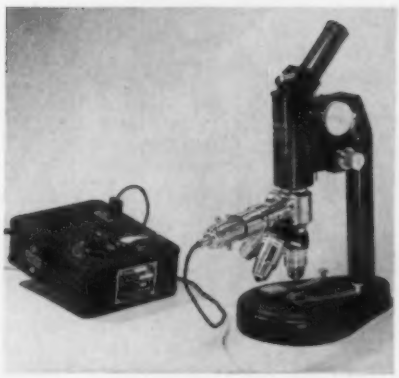

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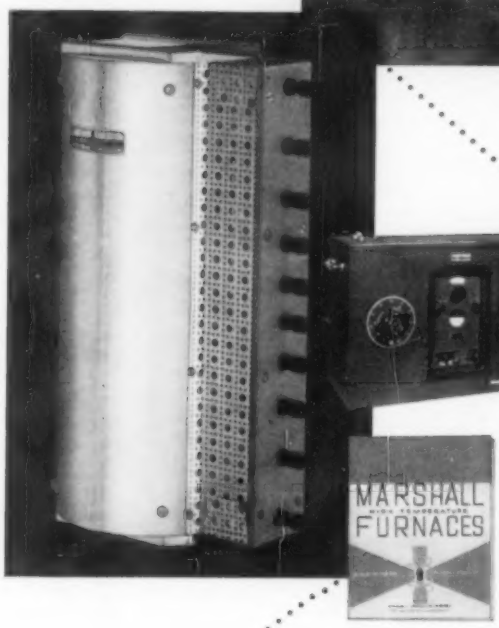

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Books

(Continued from page 88)

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Progress in Semiconductors, Vol. 2, edited by A. F. Gibson, P. Aigrain, and R. E. Burgess, *John Wiley & Sons Inc.*, $10.50, 1957—This second volume includes the following subjects: semiconductor alloys, properties of the III—V compound semiconductors, radiation effects in semiconductors, lifetimes of free electrons and holes in solids, the production of high quality germanium single crystals, impurities in germanium, high electric field effects in semiconductors, and theories of electroluminescence. Each article carries a list of references to original sources and there is a comprehensive index. The standard of the contents of the series has been fully maintained in vol. 2, while the length has been increased by one third. •

Rome Cable Manual of Technical Information, second edition, Rome Cable Corp., Rome, New York, 393 pp., $4.65.—This second edition of the manual, first published ten years ago, has been brought up to date, page by page, and contains some extensive and completely new sections, new information, and illustrations; 130 pages have been added without materially affecting the size of the book. The Guide is divided into eight sections: 1) wire and cable technical tables, 2) wire and power cable engineering calculations and data, 3) communication frequency data and calculations, 4) national electrical code data, 5) properties of metals, 6) general technical information, 7) conversion tables, and 8) cable installation practices. A 23-page alphabetical index follows.

Solid State Physics, Vol. IV, edited by Frederick Seitz and David Turnbull, *Academic Press Inc.*, 111 Fifth Ave., New York, 3, N. Y., 540 pp., $12.00, 1957.—The fourth volume of this series of reviews of important advances in solid state physics contains one paper of 196 pp. on ferroelectrics and antiferroelectrics and another of slightly less extent on the theory of mobility of electrons in solids. Three shorter papers are devoted to the orthogonalized plane-wave method, a bibliography of atomic wave functions, and techniques of zone melting and crystal growing. The footnote references accompanying the papers are indexed by authors, and there is a subject index to the volume. •

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ABSTRACTS

Institute of Metals Division of The Metallurgical Society of AIME

AIME Annual Meeting, February 16-20, 1958
New York City

• All Metallurgical Society Meetings Listed Will be Held in The Sheraton-McAlpin Hotel

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MONDAY, FEBRUARY 17, AM

DIFFUSION AND IMPERFECTIONS

9:30 am Winter Garden (24th Floor)

Sheraton-McAlpin Hotel

C. E. Birchenall and R. W. Balluffi, Associate Chairmen

A Model for Solute Diffusion in Semiconductors With the Diamond Structure: R. A. Swalin, University of Minnesota.

A theory for solute diffusion in crystals with the diamond structure, such as germanium and silicon, is derived by consideration of the electrostatic and elastic interaction between solute ions and vacancies. It is interesting to note that due to the open characteristic of the diamond lattice, no geometrical barrier to diffusion is presented as in the case of the more close-packed metal lattices and, thus the factors influencing the solute diffusion rate are considerably changed.

From a knowledge of the Fermi level and the vacancy acceptor level, the fraction of negatively charged vacancies can be calculated by application of Fermi-Dirac statistics. Thus, the probability of finding charged solute ion-vacancy pairs is markedly affected by the sign of the charge of the ion. Positive ions (donors) will attract vacancies, and negative ions (acceptors) will be repulsed. Moreover, there will be an elastic interaction between ions and vacancies. Ions that have sizes considerably different from the solvent will also attract vacancies, since their strain energy can thus be reduced. An equation, therefore, can be derived expressing the solute diffusion constant as a function of the position of the vacancy electron acceptor level and the size and charge of solute ions.

It is experimentally observed that donor ions diffuse about two orders of magnitude faster than acceptor ions in germanium, whereas in silicon, acceptor ions diffuse about an order of magnitude faster than donor ions. Because of the relation between the Fermi level and vacancy acceptor level, coulombic interaction is shown to be the predominating factor in germanium, whereas in silicon, the size difference between solute and solvent ions is shown to predominate. The agreement between theory and experiment is shown to be quite good.

Steady-State Diffusion in Substitutional Solid Solutions: A. S. Yue, The Dow Chemical Co., and A. G. Guy, Purdue University (TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME, February, 1958).

A study was made of the effects of a prolonged flux of zinc atoms through the α-solid solution of zinc in copper. The experimental arrangement consisted essentially of a copper disk about 0.01 in. thick, at one of whose surfaces a gaseous atmosphere containing zinc atoms was maintained, and at the other surface a gaseous atmosphere with a minimum of zinc atoms was maintained. During prolonged exposure at high temperatures the zinc content of the copper disk gradually built up to the steady-state concentration distribution and then remained at this value. The concentration distribution curves for various conditions were determined by chemical analyses. The results showed that the condition of steady-state diffusion was achieved. The diffusion coefficients calculated from the experimental data, although not of high precision, agreed with the values obtained by other workers using unsteady-state methods. Relatively slight porosity developed in the specimens in the course of diffusion.

Effect of Torsional Strains on Self-Diffusion in Silver Single Crystals: C. H. Lee and Robert Maddin, University of Pennsylvania.

Cylindrical single crystals of Ag (99.99), one-half in. in diameter, grown by the Bridgman method, were plated with Ag^{110}. The crystals were twisted to a constant total surface strain during the diffusion-anneal at temperatures of 600, 700, 750, and 800°C as a function of the rate of straining. The diffusivities were measured by sectioning and counting. The ratio of the self-diffusion while straining occurred (D_s) to the self-diffusion at no strain (D_o) varies linearly with rate of twisting and attains values of greater than 100 for the rates used. The enhancement of diffusion by straining is inversely proportional to the temperature at which diffusion occurs. The activation energy for diffusion (Q_D), determined from the data plotted as a function of the rate of twisting decreases from 44,000 cal per mol for zero strain, to an asymptotic value of 17,000 cal per mol for strain rates of 20×10^{-5} sec $^{-1}$. The activation energy for motion of vancancies Q_M is considered to be 17,000 cal per mol and that for formation Q_F is 27,000 cal per mol. The experimental data permitted the calculation of N_v^+, the concentration of defects in equilibrium at steady-state (equal to the thermal equilibrium number of vacancies plus those produced by deformation less the number lost due to annihiliation). Analysis, as first suggested by Cohen[1] based upon the generation of vacancies produced by the deformation will be discussed in detail.

[1] M. Cohen—private communication.

Atomic Mobility in the Alloy Cu_3Au: W. A. Goering, Ford Motor Co., and A. S. Nowick, Watson Laboratories, International Business Machines Corp.

Kinetics of stress-induced ordering in Cu_3Au have been studied by means of anelastic techniques, including low-frequency internal friction and elastic after-effect measurements. Internal friction measurements on the disordered alloy above the critical temperature, T_c, showed the usual Zener peak at a temperature of 406°C for a frequency of 2 cps. Both disordered and partly long-range ordered specimens were tested in static runs below T_c. (The disordered samples were obtained by quenching from 420°C.) The relaxation strength of the ordered specimen was much smaller than that of the disordered specimen. The activation energy for the relaxation process in the disordered alloy is found to be 43.0 kcal per mole. If the same frequency factor is taken for the relaxation in the ordered alloy as for the disordered alloy, an activation energy of 44.8 kcal per mole is obtained for the ordered alloy. The reason for such a small difference between the two activation energies will be discussed.

On the Origin of Dislocations: Doris Kuhlmann-Wilsdorf, University of Pennsylvania.

In the face-centred cubic lattice a stacking fault, caused by the condensation of vacancies on a {111} plane, is converted into a dislocation source of Frank-Read type if it is swept by a half dislocation of a kind that restores lattice order. In other major lattice types dislocation sources will also arise through the condensation of vacancies on close-packed lattice planes. It is proposed that these are the dislocation sources that release a major proportion, if not all, of the dislocations formed during plastic deformation. By introducing this kind of dislocation source several advantages are gained. For instance, for the case of aluminum—the only metal for which the relevant data are known—good quantitative agreement is found between the expected number of dislocation sources and the number of sources that apparently are active in the formation of the elementary structure. Further, all dislocation sources produced through the condensation of vacancies are of the type that gives rise to the so-called "inhomogeneous slip," in agreement with a recent experimental result obtained from α-brass. Finally, when making the assumption that vacancy condensation takes place predominantly on the most densely packed planes, one can account for all important glide systems found in crystals of the most common lattice types.

Change in Density of Copper During Creep: R. C. Boettner and W. D. Robertson, Yale University.

Volume and distribution of voids produced in polycrystalline copper, under constant-stress creep conditions, have been investigated as a function of time, temperature, and stress. The experimental technique consisted of precision density measurements on specimens after increasing amounts of creep strain at different temperatures and stresses. Metallographic observations and measurements of density as a function of radial distance from the center of the specimen were employed to determine the distribution of holes.

Changes in density were observed prior to the termination of the first stage of creep. The logarithm of the apparent volume of voids calculated from the change in density produced during the second stage of creep is a linear function of strain at each temperature (400 to 550°C) and at each stress (3000 to 5000 psi). The distribution of void volume across the specimen diameter was investigated by removing successive layers from the specimens; it appears that voids are formed first at the surface with the radial void concentration becoming more uniform with increasing time. The development of voids depends on purity of the copper and it is markedly affected by directional solidification of copper.

Quenched-In Vacancies in Noble Metals: H. Kimura, Robert Maddin, and Doris Kuhlmann-Wilsdorf, University of Pennsylvania.

Polycrystalline copper wire (99.999) 25 mils diameter quenched from 1040°C shows a small amount of initial hardening, which is considered to be due to thermal strains; about 30 pct increase in the yield stress is observed after quenching and aging at several temperatures between 95°C and 117°C. After reaching the maximum hardening the specimen shows resoftening. The activation energy for both hardening and resoftening processes is 0.7 ± 0.1eV. The same activation energy suggests that the two processes may actually be two phases of a single process, which is considered to be due to the absorption of vacancies at dislocation networks.

According to Kauffman and Meshii's research on gold[1], the hardening process occurs at a more rapid rate but with approximately the same activation energy. The amount of hardening, however, is 200 to 300 pct. The activation energy for resoftening from this hardening is, however, equal to that for self-diffusion. These facts support the idea that hardening in gold is due to the formation of sessile dislocations inside the dislocation network.

Considering the formation and growth of sessile dislocation rings by absorption of vacancies, the decay curves for vacancies to form sessile rings have been calculated as

$$N = N_o \, (\cosh \alpha k t)^{-2}$$

where N is the number of vacancies at time t, N_o is the initial number of vacancies, α is the absorption rate constant and $\alpha = \beta e^{-E_M/kT}$. E_M is the activation energy for the migration of vacancies, $K = \sqrt{\pi N_o N_s}$. N_s is the number of sessile rings, β is a constant. When the number of quenched-in vacancies is large, they meet each other to form sessile rings before ending their lifetime at dislocation networks; this process results in a hyperbolic decay. When the number of vacancies is small, they migrate mainly to the dislocation network; the resulting decay is exponential. Bauerle and Koehler's research[2] on the change in resistivity of quenched gold shows these two types of decay depending upon the quenching temperatures. Our theory explains these results and presents some new facts about the behavior of vacancies.

The mechanisms of quench hardening in copper with a low concentration of vacancies, and in gold, with a high concentration of vacancies, will be discussed in greater detail.

[1] J. W. Kauffman and M. Meshii: JOURNAL OF METALS, October 1957, 30.

[2] J. E. Bauerle and J. S. Koehler: Technical Report #8, DA-11-022-ORD-1212. Office of Ordnance Research.

Further Observations on the Formation of Intercrystalline Voids During Creep: C. W. Chen, Westinghouse Electric Corp.

Since the proposal of a mechanism of high-temperature intercrystalline cracking by Chen and Machlin[1,2], further investigation on bicrystals and polycrystalline specimens of Cu and Si-Fe has indicated that the formation of voids at grain boundaries during creep may be modified considerably by changes in the grain structure. The void formation may be pronouncedly promoted or completely prevented in an unstable structure, depending on the nature of the structure changes.

Recrystallization promotes void formation by providing a large number of sites for void nucleation. This effect is enhanced when the grains in the unrecrystallized matrix are elongated in the direction of the applied stress during creep. Voids may or may not effectively pin down the grain boundaries. When grain boundaries are anchored, the remaining intercrystalline voids will eventually join together to form macroscopic cracks. This may lead to the failure of the metal. In the case that recrystallized grains are free to grow, voids may be observed within grains and the formation of voids is not fatally harmful to the ductility and the rupture life of the material.

Grain boundary migration, on the other hand, prevents the formation of intercrystalline voids, due to the accompanying stress relaxation. Consequently, not only is the void formation minimized or eliminated, but also the mode of fracture changes with increasing temperature from intercrystalline to ductile and transcrystalline.

[1] C. W. Chen and E. S. Machlin, *Acta Metallurgica*, vol. 4, No. 6, p. 655 (1956).
[2] C. W. Chen and E. S. Machlin, JOURNAL OF METALS, vol. 9, No. 7, p. 829 (1957).

Intergranular Cavitation in Stressed Copper-Nickel Alloys: B. J. Reid, Metal Manufactures Ltd., Port Kembla, New South Wales, Australia, and J. N. Greenwood, University of Melbourne, Australia.

Cavities are formed in the grain-boundaries of copper and 70:30 brass (as well as in magnesium) by the application of tensile stresses at elevated temperatures. For a given rate of strain, cavities are formed in brass at a lower temperature than in copper, and they are larger; it was thought that this earlier onset of cavitation in the alloy might be caused by the distortion produced in the metal lattice by the alloying element.

If the cavitation is caused by the vacancy migration mechanism, the distortion of the lattice would reduce the energy required for vacancy formation, and thus provide vacancies more readily to assist in the cavitation process.

Evaporation of Silver Crystals: J. P. Hirth and G. M. Pound, Carnegie Institute of Technology.

The flux of evaporation J from {100}, {111} and {100} planes of silver single crystals and from polycrystalline specimens was measured at 744°C under a high vacuum using a time average weight loss method. Constancy of evaporation rate with time was demonstrated by continuous rate measurements. The evaporation coefficient α was computed from the measured flux and vapor pressure data through the relationship $J = \alpha p_e/\sqrt{2\pi mkT}$. The evaporation coefficients for the close packed planes and the polycrystalline specimens were found to be about 0.3, providing partial confirmation of the theoretical limiting law for evaporation of perfect crystals, $\alpha = 2/3\left(\frac{p}{p_e}\right) + 1/3$. The {110} planes faceted to form {100} and {111} planes, resulting in a greater evaporating area and an α of about 0.4.

The thermal etch pit density on the {100} and {111} evaporated surfaces was observed to be about 10^6 per sq cm. Presumably these were due to dislocations with a screw component normal to the evaporating surface. The failure of these monatomic ledge sources to cause a significant positive departure from the limiting law is consistent with the theoretical prediction based on a dislocation spiral mechanism. It is shown that Langmuir type vapor pressure measurements can be in error by as much as a factor of three, depending on the degree of perfection of the evaporating surface.

The evaporation morphology of the plane surfaces and the surfaces of spherical single crystals is described in some detail.

MONDAY, FEBRUARY 17, PM

SYMPOSIUM ON HIGH-SPEED STRESSING OF SOLIDS—CONTRIBUTED PAPERS

2:30 pm — Ballroom (24th Floor)

Sheraton-McAlpin Hotel

J. C. Fisher and K. A. Jackson, Associate Chairmen

Use of an Explosive Press for Impulsive Loading Studies: E. W. LaRocca and John Pearson, U. S. Naval Ordnance Test Station.

Small, explosively-activated presses have been used as research tools in the study of materials behavior under impulsive loads. Features of the press include double-opposed pistons and positive retention of the test specimen. The press, which is of a sandwich type construction, uses two explosive charges fired simultaneously to drive two opposed pistons together into a central steel cylinder in which the specimen material has been placed. Estimates of the pressures which can be obtained are of the order of several million psi. The impulse imparted to the specimen can be varied by confinement of the explosives, by the size and geometry of the charges, and by modification of the press design. Presses of this type are extremely useful in the study of materials such as powdered metals that are difficult to work with under normal explosive loading techniques. Operation of the press and its application to the study of several materials are described.

High-Speed Motion of Dislocations in LiF Crystals: J. J. Gilman and W. G. Johnston, General Electric Co.

We have described previously how isolated dislocations can be put into LiF crystals and observed by means of etch-pits. By etching such isolated dislocations, then applying short stress pulses to them, and finally re-etching to disclose their final positions; we can observe dislocation motion at high velocities. The velocity is very sensitive to the applied stress. Using various methods for applying short stress pulses we have measured dislocation velocities in the range from less then 1 A per sec up to 10^8 A per sec and have made preliminary observations of dislocations moving at speeds up to 6×10^{11} A per sec. Dislocation velocity increases very rapidly with increasing applied stress but we expect the velocity to saturate at some value less than 6×10^{12} A per sec (sound velocity).

Explosive Deformation of Low-Carbon Steel: Samuel Katz and D. R. Curran, Stanford Research Institute.

Deformation of low-carbon steel produced by contact detonation of a slab of explosives was studied by terminal observation, metallographic examination, and high-speed photographic measurement of the Hugoniot equation of state. At the explosive-metal contact a narrow, work-hardened zone is produced, with a microstructure of profusely twinned grains, as suggested by resemblance to Neumann bands. A profile of twin density from the contact surface inward shows an abrupt decrease in twin density at the edge of the zone. In the six specimens on which dynamic measurements were made, this decrease occurred in the neighborhood of 140,000 kg per sq cm, suggesting the existence of a critical stress for producing such contact zones. These and other dynamic measurements have indicated the existence of a multiple shock system in iron, possibly produced by the reversible transition of α-iron to γ-iron. Profusely twinned contact zones may be associated with this transition. Such zones are also produced by internal shock collision.

Preferred twin orientation is observed in all specimens. In contact zones, twins tend to align parallel to the shock front. In profusely twinned grains, there are usually two or more twin directions, less than 60° to the shock front.

Effect of Carbon and Manganese Content on High-Speed Flow Properties of Mild Steel: A. M. Sullivan and J. M. Krafft, U. S. Naval Research Laboratory.

The influence of additions of carbon and maganese on the ductility transition of plain carbon steel is well known. In general increased carbon will raise the transition temperature; increased manganese will lower it. Both tend to increase flow strength for steels of constant grain size. Postulates of a Ludwig criterion for fracture initiation would lead one to question whether the differing fracture behavior incident to additions of these elements would be reflected in differing flow stress characteristics at high-strain rates.

Uniaxial compression at straining speeds from 5 to 500 per sec has been applied to steels of carbon content varied from 0.01 to 0.30 pct and manganese varied from 0.50 to 1.50 pct. For the range above 50 per sec a Hopkinson bar loading device was employed; lower strain rates were obtained with a gunpowder pressure-loaded jig of special design.

The results indicate a correlation between flow stress at a given low-strain rate and the sensitivity of flow stress to change in strain rate. This relationship, suggested in 1946 by G. I. Taylor[1], appears to hold even though the factors similarly influencing flow stress, and thus the strain rate sensitivity of flow stress, have divergent influences upon the transition temperature. Oher criteria in the relationships between high-speed flow and fracture ductility transition would appear to be necessary.

[1] G. I. Taylor, *J. Inst. Civil Eng.* V26, No. 80 (Oct 1946), pp 486-519.

Microstructure of Metals Subjected to Intensive Plane Shock Waves: Cyril S. Smith, University of Chicago.

Through the cooperation of Messrs. Walsh, Fowler, Duff *et al.* of the Los Alamos Scientific Laboratory, samples of polycrystalline copper, iron, and other materials have been subjected to shock pressures as high as 600 kilobars. Despite transitory volume changes of over 20 pct, the samples are recovered with little permanent deformation or distortion. Copper shows unmistakable mechanical twinning. Iron displays simple Neumann bands after low-pressure shock, and a complex array of bands (perhaps due to a reversed transformation) above a certain critical pressure. The markings are directionally oriented in relation to the shock. Experiments will be reported in which inclined shocks are used to separate the effects of the compression and rarefaction waves. Hardness and annealing data will be given. The possible structure of the interface between high and low-density material will be discussed, and the manner of its translation to produce the necessary lattice parameter changes.

Fracture of Aluminum Under Explosive Loads: R. S. Davis, Harvard University.

The mechanical behavior of high-purity and commercial-purity aluminum single crystal and polycrystalline specimens was studied under explosive loading conditions. The loading is of the plane shock wave type.

The single crystal specimens fractured at approximately twice the stress level required to fracture the polycrystalline specimens. The stress for fracture of the latter decreased with decreasing grain size. The purity of the aluminum did not have an observable effect on the stress for fracture.

Results of Some Impact Experiments: Enrico Volterra, University of Texas.

Results of experiments on impact of spherical balls and short round-end cylindrical bars on long cylindrical bars for different impact velocities are described. Use of electric strain gage equipment made it possible to determine with great accuracy not only contact times (pulse lengths), as done in previous experiments, but also stresses as functions of time. Theoretical analysis of impact phenomena were directly compared for all portions of the experimentally induced pulses. Some apparent discrepancies between theoretical and experimental findings were explained.

Explosive-Induced Fracture: J. J. Kelly, Stanford Research Institute.

In the explosive-induced fracture of ductile metals both cleavage and ductile fractures have been observed. When fracture results from shock wave collision the fractures are always of the cleavage or brittle type. A series of spalling experiments will be discussed[1] in which some of the spalled surfaces appeared rough and some as smooth as a rolled surface. The microscopic appearance of both types is essentially the same. The difference in appearance results in the difference in cross-sectional area over which the conditions required for fracture are distributed. When these conditions are distributed widely enough the fractures appear as a great number of very short segments. These segments have no definite relationship in length and direction to grain size, orientation, grain boundaries, or ferrite mean free path. The location of some of the segments does not agree with the theory that cleavage fracture always originates by the formation of Griffith cracks at grain boundaries due to piled-up dislocations.[2] These segments appear within grains remote from grain boundaries. Evidence of the sudden release of thermal energy at crack surfaces in shock-loaded α-brass was observed as a change in microstructure and, based on observed color, a decrease in zinc content.

[1] E. B. Daily, Poulter Laboratories Int. R. 037-56, March 7, 1957.
[2] N. J. Petch, *Progress in Metal Physics*, Vol. 5, p. 14.

Roll Compacting of Pure Nickel Strip From Powder: J. A. Lund, University of British Columbia.

Nickel strip of excellent mechanical properties has been prepared by the direct roll-compacting of pure nickel powder, followed by sintering and cold re-rolling of the as-compacted product.

Coherent *green* strip was produced in the initial roll-compacting operation, and the effects of metal powder particle size, roll gap, and rolling speed on the density of the as-compacted strip are reported. Green strip density varied from 77 pct to 88 pct of the theoretical density of pure nickel. The microstructure of the green strip indicated that the hard nickel powder particles had not been plastically deformed in the rolls, but that many particles had fragmented in a brittle manner. The coherency of the as-compacted material, which permitted it to be handled quite readily in short lengths, has been attributed mainly to mechanical interlocking of the metal particles.

The effects on strip properties of sintering at several temperatures for various times, and of progressive cold re-rolling after sintering, have been studied. Sintering temperatures of 1900° to 2250°F for corresponding times of 30 to 15 min have been found to be suitable, followed by a total cold reduction of 65 to 75 pct in the thickness of the sintered strip, with intermediate and final annealing at 1600°F for 30 min. With this treatment, strip has been obtained with values of density, tensile strength and ductility that are at least as high as those reported for cast, rolled and annealed pure nickel. Best properties were observed in strip which had been roll-compacted originally from the finer grades of nickel powder. Other roll-compacting variables appeared to have almost no effect on the properties obtainable after sintering and extensive cold re-rolling.

Densified and annealed strip has been reduced up to 45 pct in thickness by cold rolling without annealing. Tensile strength of the strip rose to 85,000 psi with this treatment.

MONDAY, FEBRUARY 17, PM

DEFORMATION

2:30 pm Winter Garden (24th Floor)

Sheraton-McAlpin Hotel

W. C. Ellis and F. D. Rosi, Associate Chairmen

On the Strain-Hardening of Aluminum Single and Bicrystals: R. S. Davis and U. F. Kocks, Harvard University.

Single crystals and non-symmetric iso-axial bicrystals of 99.99 pct Al were strained to failure. The results of Davis, Fleischer, Livingston and Chalmers[1], are confirmed for high strains in that there is no difference between the strain-hardening behaviour of single and bicrystals of the tensile orientations <211>, <110>, <111>, and <100>; for the orientations <0.5>, <321>, and <221> the difference generally decreases at higher strains. Bicrystals of <210> orientation harden more than the corresponding single crystals. This indicates that bicrystals of all those orientations harden more than the corresponding single crystals for which the single crystals show easy glide. A few observations on the behaviour of the single crystals at high deformations will be discussed.

[1] R. S. Davis, R. L. Fleischer, J. D. Livingston, and B. Chalmers: *AIME Trans.*, 1957, Vol. 209, p. 136; Journal of Metals, January 1957.

Creep Characteristics of Magnesium Single Crystals in the Temperature Range of 78° to 364°K: Hans Conrad, Westinghouse Electric Corp., and W. D. Robertson, Yale University.

This paper presents certain features of the creep behavior of Mg crystals observed during incremental loading creep tests in tension and shear in the temperature range 78° to 364°K. The creep curves were transient in character and exhibited waves or periodic behavior, especially at small strain rates (10^{-5} — 10^{-4} min^{-1}). A sigmoidal curve was frequently observed for one of the early curves following the first occurrence of creep, indicative of a yield phenomenon. Repeating or duplication of segments of the creep curves was observed at all temperatures indicating that identical conditions for flow existed after various stress and strain histories. The stress and creep strain were linearily related through the strain-hardening coefficient h.

At 78° and 203°K a straight line of slope $-Bh$ (where B is a constant independent of temperature) was obtained when the logarithm of the creep rate was plotted versus the creep strain. Further, the time law for creep at these temperatures was logarithmic with the slope α independent of temperature. The temperature independence of α and B represents a serious objection to the theory of low-temperature creep based on the intersection of dislocations. At 298° and 364°K a parabolic (power) law with exponent m = 0.4—0.8 was approximated. The departure from logarithmic creep was attributed to recovery which was observed at 298°K and 364°K but not at the lower temperatures.

An analysis of the creep curves yielded the following equation for the creep rate:

$$\dot{\gamma} = C \exp\left(\frac{-\Delta H}{kT}\right) \exp B(\tau - h\gamma)$$

where B and C are constants, τ the applied stress, h the strain-hardening coefficient, γ the strain and ΔH an activation of 10 ± 1 Kcal per mole.

An Investigation of the Rate Controlling Mechanism for Plastic Flow of Copper Crystals at 90°K and 170°K: Hans Conrad, Westinghouse Electric Corp.

Plastic flow characteristics of copper single crystals at 90°K and 170°K were investigated by means of incremental loading creep tests and change-in-strain-rate tension tests for the purpose of determining whether the intersection of dislocations is the rate-controlling process in low-temperature deformation. The present results indicate that although the nature of the stress function is similar to that predicted by the intersecting mechanism, i.e. strain rate = C exp. B $(\tau - \tau_0)$, the constant B is relatively independent of temperature rather than porportional to the reciprocal of the temperature as required by the theory. This represents a serious objection to the theory.

An analysis of the present data along with data of previous investigators indicates some agreement with a rate controlling mechanism based on the formation of thermal kinks in dislocations lying in close-packed directions. Several difficulties associated with the application of this mechanism to plastic flow are discussed.

Deformation of Aluminum Single Crystals in Shear: W. L. Phillips, Jr., and W. D. Robertson, Yale University.

Aluminum single crystals, strained in direct shear and in tension, have comparable critical resolved shear stresses and show a similar orientation dependence of the stress strain curve, when the ratio of diameter to length in shear is sufficiently large. Sheared crystals exhibit asterism in Laue patterns after small strains and complete recovery of mechanical properties cannot be obtaind by annealing. The density of slip lines observed in direct shear and in tension is essentially the same.

Crystals were strained various amounts in a close-packed slip direction, unloaded and immediately strained in a second slip direction 60, 120, or 180 degress from the original slip direction. The results show that there is no barrier to slip in any of the latent close-packed directions, during either the easy glide or the parabolic ranges of the stress strain curve. The absence of barriers is discussed as a possible explanation for the absence of a linear range, following easy glide, in the stress-strain curve of aluminum at room temperature.

Dislocation Structure of Slip Bands in Iron: J. R. Low, Jr., General Electric Co.

By means of an etch-pitting technique the dislocation structure of slip bands in single crystals of 3 pct Si-Fe has been determined. It was found that slip bands are composed of short, overlapping, regions of homogeneous slip in which the screw dislocations from a single source move about 1 to 3 μ while the edge dislocations move much larger distances, up to 25 or 50 μ. Slip does not occur by a large number of loops spreading out from a single source and covering the whole of a slip plane. Rather, some 10 to 20 loops

may be generated in a concentric array and then another source is activated on an adjacent plane, the loops from this source overlapping the original set. By this mechanism the slip spreads across a crystal leading to a slip band having a finite width and made up of small arrays of dislocation loops which are substantially coplanar.

The edge components of a given set of dislocation loops move in the close-packed plane leading to straight slip lines on those crystal faces normal to the edge dislocation lines. On the other hand, the screw components may move on any plane and where local distortions of the shear-stress pattern occur, as, for example, where slip bands overlap, the screw components follow curved paths. It is this latter behavior of the screw components which gives rise to the typical wavy slip lines of iron.

Slip Line Measurements on Alpha-Brass Single Crystals: J. T. Fourie, National Physical Laboratory, Pretoria, South Africa, and H. G. F. Wilsdorf, Franklin Institute.

The slip line pattern of deformed α-brass is markedly different from that of pure fcc metals which exhibit *elementary structure* and slip bands. On α-brass, on the other hand, slip lines appear in clusters but no slip bands or elementary structure have been observed; occasionally very deep slip lines with glide distances of up to 20,000 A and a considerable amount of cross-slip have been found.

Careful measurements have been carried out on electron micrographs which were taken from identical sections of single crystals after increasing the strain by certain amounts. The results with regard to the dependence of (1) the density of active slip planes, (2) the average glide per slip line, and (3) the frequency distribution of slip lines of given depths on strain and stress will be presented. A discussion of the experimental data will be given.

Room-Temperature Deformation Processes in Zirconium: E. J. Rapperport, Nuclear Metals, Inc.

A study has been made of the deformation processes active in zirconium deformed in tension and compression at room temperature. The work was performed on single crystals and on large-grained samples of relatively high purity. Iodide crystal-bar zirconium was used, with some samples being made from arc-melted stock, and some from the crystal-bar as grown.

After removal of hydrogen from the zirconium by dynamic vacuum annealing, two methods of crystal production were employed. One method was to maintain the samples at 840°C *in vacuo* for eight to ten days; the other was to cycle the samples two or three times between 1200°C and 840°C, remaining at the higher temperature for about four hours, and at the lower for five days. These techniques yielded grains as large as 0.2 x 0.2 x 0.7 in., which were of satisfactory quality as judged by the sharpness of spots on Laue back-reflection photographs.

The only slip system observed was $(10\bar{1}0)[\bar{1}2\bar{1}0]$ with a critical resolved shear stress for slip of about 0.65 Kg per sq mm in compression. Although a wide distribution of crystal orientations was used and some crystals were particularly well oriented for basal slip, no slip of this type was observed. The active twin planes were $(10\bar{1}2)$, $(11\bar{2}1)$, $(11\bar{2}2)$, and $(11\bar{2}3)$. Experimental determinations were made of the twin indices for $(10\bar{1}2)$, $(11\bar{2}1)$, and $(11\bar{2}2)$ twins. The experimental shear magnitudes found for these three types of twins are about 0.17, 0.21, and 0.23, respectively, and the shear directions for the planes as written above are $[10\bar{1}1]$, $[11\bar{2}6]$, and $[11\bar{2}3]$, respectively. The extreme narrowness (1 to 2 μ) of the $[11\bar{2}1]$ twins caused considerable experimental difficulty and as a consequence the twin indices for this family are less certain than for the others.

Temperature Dependence of the Flow Stress in Age-Hardened Al-4 Per Cent Cu Single Crystals: Anthony Kelly and C. Chiou, Northwestern University.

Measurements have been made of the temperature dependence of the critical resolved shear stress of aged Al-4 pct Cu single crystals. By changing the temperature during a tensile test it is also possible to measure the reversible change of flow stress with temperature during deformation. The experiments have been carried out over the temperature range 77°K to 373°K for crystals age-hardened various amounts. Although the flow stress of these crystals is always an order of magnitude higher than the flow stress of single crystals of pure aluminum the temperature dependence of the flow stress of crystals containing GPI zones is surprisingly similar. It is concluded that the elementary process governing the rate of flow is the same in both alloy and pure metal.

Creation of Cleavage Steps by Dislocations: J. J. Gilman, General Electric Co.

By comparing cleavage-step patterns and dislocation etch-pit patterns in LiF crystals, it is shown that screw dislocations always produce cleavage steps on fractured surfaces. Edge dislocations do not have this effect. Using cleavage-step patterns as a tool, the phenomenon of crack nucleation of dislocations was investigated. It was found that out of 32 kinds of crystals, cracks nucleated dislocations in 25 kinds, 5 cases were doubtful, and no evidence of crack-nucleated dislocations could be found in 2 kinds.

Yielding in Zinc Single Crystals: Norman Brown, University of Pennsylvania.

It is proved that the macroscopic yield point in zinc single crystals is associated with the stress to move a dislocation and not with the stress to generate a dislocation. The proof rests on a rigorous analysis of the Parker-Washburn experiment in which the stress to move the existing dislocations in the low-angle boundary is equal to the ordinary yield point determined by a tensile or shear test.

In the Parker-Washburn experiment the specimen is loaded as a cantilever beam of rectangular cross-section with basal plane being parallel to the neutral plane and having a low-angle boundary perpendicular to the basal plane. As the load, L, moves through a vertical displacement, v, the boundary moves a distance, $v/\sin\theta$, where θ is the tilt of the low-angle boundary. If $b\tau$ is the force per unit length which resists the motion of each dislocation in the boundary, then the total force resisting the entire boundary is $b\tau wN$ where the w is the width of the beam and N is the number of dislocations in the boundary. By the principle of vertical work the external work Lv is equal to the internal work, $b\tau wNv/\sin\theta$. Since $\sin\theta = b^N/h$ where h is the beam height

$$\tau = \frac{L}{hw}$$

This is the experimental result obtained by Parker-Washburn where τ was equal to the ordinary critical resolved shear-stress determined by a shear or tensile test. This proves that the macroscopic yield point in zinc is associated with the resistance of the lattice to dislocation movement and not w, the generation of dislocations.

TUESDAY, FEBRUARY 18, AM

MECHANICAL PROPERTIES

9:00 am — Crystal Room (1st Mezzanine)

Sheraton-McAlpin Hotel

Norman Brown and J. W. Frederickson, Associate Chairmen

Effect of Copper, Nickel, Iron, and Chromium on the Tensile Properties of Preferentially Oriented Beryllium Sheet: F. M. Yans and A. R. Kaufmann, Nuclear Metals, Inc., and A. D. Donaldson, Atomics International.

Beryllium was mixed with copper, nickel, iron, and chromium to form binary alloys in powder form, then extruded and cross rolled. The effect of each alloying element was determined by tensile testing. In solid solution, small amounts of iron and nickel had an embrittling effect, while copper in solution increased the strength but had no effect on ductility. The chromium was not in solid solution but it had an embrittling effect as a precipitate. The planes and modes of fracture were investigated.

Effect of Composition and Heat Treatment on the Uniform Elongation and Flow Properties of Alpha-Beta Titanium Alloys: A. J. Griest, H. A. Robinson, and P. D. Frost, Battelle Memorial Institute. (TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME, February, 1958).

The flow characteristics and uniform elongation of alpha-beta titanium alloys in the solution-treated condition were shown to be markedly affected by the solution temperature. Two classes of alpha-beta alloys were distinguished based on the effect of solution temperature on the uniform elongation. Martensitic alpha-beta alloys, which are relatively weakly beta-stabilized, showed decreasing values of uniform elongation as the solution temperature was initially increased. However, after solution treatment at still higher temperatures in the alpha-beta field, the uniform elongation of these alloys was again high, and often attained its maximum value. Non-martensitic alpha-beta alloys, which are more heavily beta stabilized, showed a continuous decrease of uniform elongation with increasing solution temperature. The behavior was rationalized in terms of the alpha-beta ratio and the alloy content of the beta existing at the solution temperature. The data indicate that in commercial practice close temperature control may be required to get maximum uniform elongation, and, hence, maximum potential formability, in solution treated sheet. Bend test data were also obtained for the solution-treated conditions. In addition, data on the effect of aging treatments following the solution treatments are presented to show the level of strength and ductility which might be attained in sheet parts formed in the solution-treated condition and aged to produce high strengths.

Some Mechanical Properties of Zone-Refined Titanium in the Temperature Range From 298° to 4.2°K: J. L. Rutherford, M. Herman, and R. L. Smith, Franklin Institute.

Tensile properties of zone-refined iodide titanium have been evaluated in the temperature range from 298° to 4.2°K. It has been found that the higher the purity, the lower the flow stresses and the better the low-temperature ductility. Reduction of area up to 93 pct and elongations of 53 pct at −196°C have been observed. The major portion of the ductility at low temperature arises from twinning, resulting in a strongly serrated stress-strain curve. The hardness of the titanium was lowered by purification. The softest point in the zone refined bar was found at the 10 pct point.

Some mechanical properties of zone-refined titanium in the temperature range from 298° to 4.2°K are presented.

Observation of a Transition-Point in the Plastic Deformation of Polycrystalline Iron: J. C. Wijman, The Dow Chemical Co., and M. Gensamer, Columbia University.

A study of the tensile characteristics of electrolytic polycrystalline iron has disclosed a discontinuity in the true stress—true strain curves. Such a discontinuity or "transition point" has been reported previously for polycrystalline aluminum.

Tensile experiments were performed using specimens of nonconventional geometry in order that the early stages of deformation would not be obscured by inhomogeneous yielding. The experiments were conducted over a range of temperatures from 135°K to 300°K and over a range of time rates of extension varying from 0.002 in. per minute to 2 in. per minute.

The strain at the transition point was found to increase with decreasing temperature, being 0.04 at 300°K and 0.10 at 157°K; no variation with strain rate could be detected at any temperature. Microstructural observations indicated that the transition-point strain coincided with the general onset of cross-slip in the grains.

Effect of Hot Working on the Structure and Creep-Rupture Properties of Heat-Resistant Alloys: A. P. Coldren and J. W. Freeman, University of Michigan, and C. B. Hartley, Wright Air Development Center.

Hot working can be used to vary the creep-rupture properties of alloys in the as-worked condition over wide ranges. Data have been obtained on commercially pure nickel (*A* Nickel) indicating that during isothermal hot working the per cent reduction has a much greater influence on properties at 1100°F than does the temperature of working, provided that recrystallization does not occur during working or testing. The results do not correlate perfectly with simple measures of strain hardening. Preliminary structural studies indicate a likely, added influence of substructures.

Certain alloys show a pronounced effect of hot-working conditions even when solution treated and aged after hot working. Data are presented for A-286 alloy in the solution-treated and aged condition that show the influence of the prior hot-working temperature and reduction under isothermal conditions. For example, a ten-fold variation in the rupture life at 1200°F and 65,000 psi was effected by variations in prior working conditions. Preliminary results of structural studies to identify the mechanism will be given.

The hot-working conditions employed in this investigation cover the usual ranges of temperature and reduction that usually involve working below the temperature of simultaneous recrystallization. Therefore, the present study is not confined to temperatures at which recrystallization occurs during working.

Preparation and Properties of Europium: F. H. Spedding, J. J. Hanak, and A. H. Daane, U. S. Atomic Energy Commission, Iowa State College

A quantity of 70.4 g of europium metal of high purity was prepared by heating Eu_2O_3 with lanthanum metal *in vacuo* at 1200°C. The melting point obtained by thermal analysis was found to be 826 ± 10°C. The rough values of coefficient of thermal expansion were 25 x 10^{-6} and 26 x 10^{-6} $(°C)^{-1}$ for the temperature ranges 77 to 300°K and 293 to 1053°K, respectively. The rough value of the change of volume on melting was found to be 4.8 pct. The electrical resistivity was determined for the range 28 to 208°C, the room temperature resistivity being 81.3 x 10^{-6} ohm-cm. The vapor pressure was determined as a function of temperature; the resulting data of the vapor pressure were fitted to a straight line, yielding the expression

$$\log P_{mm} = \frac{(-8{,}982 \pm 16)\,(8.160 \pm 0.027)}{T},$$

where P is the vapor pressure in millimeters of mercury, and T is the absolute temperature. The calculated boiling point is 1,762°K is 41,866 ± 75 cal. X-ray diffraction studies showed the metal to be b. c. c. as previously reported and the lattice constant was found to be 4.5820 ± 0.0004 A. Compression measurements were made up to 12,000 kg per sq cm pressure at 77 and 300°K and the compressibilities found were 5.54 x 10^{-6} and 7.23 x 10^{-6} atm^{-1}, respectively. Europium reacts rapidly in moist air, forming $Eu(OH)_3{\cdot}H_2O$, and the reaction follows a linear law.

TUESDAY, FEBRUARY 18, AM

STRUCTURAL PROPERTIES OF METALS AND ALLOYS (I)

9:00 am — Colonial Room (3rd Floor)

Sheraton-McAlpin Hotel

Harold Margolin and L. S. Castleman, Associate Chairmen

Eutectic Solidification Structures: H. W. Weart, Westinghouse Electric Corp., and D. J. Mack, University of Wisconsin

During a study of eutectic solidification, it was found necessary to distinguish three structures: grain structure, eutectic structure and colony structure. The first two are well known: the grain structure is analogous to the polycrystalline structure of a pure metal in that each grain grows from a single nucleus; eutectic structure describes the shape of the individual phase particles. Colony structure is a little-known subgrain structure whose units are distinguished principally by the phase particle arrangement within each unit.

The origin of the colony structure and its response to various growth conditions was studied by unidirectionally solidifying specimens of Al-Zn, Al-$CuAl_2$, and Sn-Zn eutectics. Colonies in all three alloys were generated by the movement of a solid-liquid interface consisting of blunt protuberances or *cells* whose shape is a function of the alloy system. In the Al-Zn and Al-$CuAl_2$ eutectics, cells were densely packed on the interface, roughly equiaxed and 200 to 400 μ in diameter. Sn-Zn cells were ridged and lenticular in shape, 50 to 100 μ wide and 10 to 20 times as long. Other, more equiaxed shapes were observed on Sn-Zn interfaces but their existence was transitory.

Increasing the parameter, V/G, where V is growth velocity and G is temperature gradient in the liquid, produced small and erratic changes in cell size and depth of the grooves outlining the cells. Colonies responded to similar changes in V/G by deviating strongly from the specimen axis and displaying more irregular boundaries.

The observed phase particle arrangement within the colonies is explained by simple geometrical arguments based on the presence of cells. It is suggested that the cells are a consequence of *constitutional supercooling* of the liquid adjacent to the solid-liquid interface because of the rejection of impurities by the composite interface.

Grain Boundary Migration in High-Purity Lead Crystals: K. T. Aust and J. W. Rutter, General Electric Co.

Observations are presented on grain boundray migration in zone-refined lead crystals, grown from the melt, which contain lineage or striation substructure. It was found that this substructure will support grain boundary migration and provides a constant driving force for grain boundary mobility studies. A substructure driving force as little as 2000 ergs per cm^3 (0.001 cal per gm atom) is sufficient to support grain growth. A technique for obtaining high-purity metal crystals free of striation substructure is suggested, since the striations are removed by the migration of a grain boundary through the striated crystal.

Impurities in solid solution, e.g. tin in lead, have a large effect on boundary movement. The rate of grain boundary migration was reduced by a factor of ten with the addition of 0.001 wt pct tin to the zone refined lead, while boundary migration at the expense of the substructure was stopped when 0.015 pct tin or higher was introduced. It is concluded that the mobility of a grain boundary under a small driving force is very sensitive to solute atoms at low concentrations.

New grains, which are introduced by artificial nucleation, and which grow preferentially into crystals containing substructure, have random orientations except that orientations near that of the matrix single crystal or its twins are avoided. Hence, the oriented growth theory does not appear to apply to the case of artificially nucleated grains which grow at the expense of substructure in high-purity lead crystals.

Effect of Orientation on Strain-Induced Boundary Migration in Silicon-Iron Bicrystals: K. T. Aust, E. F. Koch, and C. G. Dunn, General Electric Co.

Very little is known about the effect of grain orientation on strain-induced grain boundary migration, or about the strain energy of the individual grains. In the present paper, observations are presented on a series of silicon-iron bicrystals, in which each bicrystal contained a grain with the (110) [001] orientation.

Bicrystals of silicon-iron (3-¼ pct Si) having controlled orientations were cold-rolled 7 pct and annealed at 1100°C. The direction of boundary migration was found to depend on grain orientation for a series of orientations related by a common [1$\bar{1}$0] axis. The *cube-on-edge* or (110) [001] grain grew when the adjacent grains were about 25° to 35° away, rotations being about the [1$\bar{1}$0] axis, but was consumed when the adjacent grain was 15° away or in the (552) [11$\bar{5}$] orientation. The internal structure of the individual grains, which contributes to the driving force for boundary migration, was studied by X-rays, and by an electroetching method that revealed sub-boundaries and the sites of individual dislocations. The residual strain energy is considered to depend on both size and misorientation of subgrains. It is concluded that the residual strain energy of a grain decreases as the initial orientation varies from (110) [001] to (552) [11$\bar{5}$], and then increases and reaches a maximum near (111) [11$\bar{2}$].

Cellular Substructure in Zinc Single Crystals Grown From the Melt: V. V. Damiano and M. Herman, Franklin Institute.

Cellular substructure observed in metal crystals grown from the melt have been studied extensively by numerous investigators and have been found to be a result of constitutional supercooling of the liquid ahead of the solidifying interface affected by the quantity of solute, the rate of growth and the temperature gradient in the liquid.

Studies conducted at this laboratory have shown that the addition of small quantities of cadmium of the order of 0.1 to 99.999 pct pure zinc enables the substructure to be revealed by etching techniques in crystals grown under carefully controlled growth conditions. Decanted interfaces obtained by rapidly accelerating the solid from the liquid often reveal an obscure degenerate substructure as a result of incomplete separation of the liquid from the solid. Subsequent etching of these surfaces reveal a clearly well-defined network of cells.

Observations made on crystals grown with the (0001) plane parallel to the growth axis exhibit three types of substructure. These cells can be described as being elongated in a direction parallel to

the basal plane due to anisotropic growth velocities. Variations in the cell morphology appear as a result of differences in the mode of stacking of cells. Observations of cell stacking seem to suggest a preferred nucleation or a preferred growth phenomenon.

Etching techniques have also been used to investigate sections behind the decanted interface. These sections show that the cellular substructure degenerates into parallel bands of etch pits.

Effects of the Proeutectoid Ferrite Reaction on the Formation of Pearlite: H. I. Aaronson, Carnegie Institute of Technology.

Interactions between the proeutectoid ferrite and the pearlite reactions have been investigated primarily from the viewpoint of the mechanisms through which the proeutectoid reaction can reduce the rate of formation of pearlite. A coarse grained 0.29 pct C, 0.76 pct Mn steel, in which the ferrite reaction can compete successfully with the pearlite reaction over a wide range of reaction temperatures, was used for this purpose.

Although Dubé has shown that pearlite nucleates preferentially, and perhaps only at the interphase boundaries of proeutectoid ferrite crystals in plain carbon, hypo-eutectoid steels, it was found that the nucleation of pearlite is markedly inhibited at the boundaries of closely spaced ferrite sideplates. Pearlite nucleation was observed to occur even less frequently at intragranular ferrite plates. An intermediate rate of nucleation develops at ferrite plates nucleated at austenite twin boundaries. The growth of pearlite from the region of the grain boundaries into the interiors of austenite grains is severely restricted at low temperatures (625°C and below) by the development of interlocking networks of intragranular plates.

An explanation for the inhibition of pearlite nucleation between ferrite sideplates has been proposed in terms of the influence of the volume strain energy of transformation on the rate of nucleation of pearlitic cementite. The low pearlite nucleation rate at intragranular plates and the intermediate rate at twin boundary plates can be rationalized as an effect of the orientation-dependence of the energy of austenite-ferrite boundaries.

The overall effect of transformation temperature on the competition between the proeutectoid ferrite and the pearlite reactions was evaluated by determining the portion of proeutectoid ferrite in fully reacted specimens as a function of austenite grain size at several temperature levels.

Solubility and Precipitation of Vanadium Nitride in Alpha and Gamma Iron: R. W. Fountain, Electro Metallurgical Co., Div. Union Carbide Corp., and John Chipman, Massachusetts Institute of Technology.

The solubility of nitrogen in iron and iron-vanadium alloys containing 0 to 0.5 pct V was determined by the Sieverts' technique for temperatures of 750°C to 1200°C. Results for pure iron agree with earlier data. The limit of solubility of vanadium nitride (VN) depends on whether it is determined under conditions of increasing or decreasing nitrogen pressure. The hysteresis observed is attributed to the initial precipitation of small particles of VN which are in metastable equilibrium with a solid solution of high-nitrogen content. These particles grow as the nitrogen content of the alloy is increased, by increasing the nitrogen pressure of the system, and attain a size approaching that of the bulk equilibrium nitride. The subsequent decomposition of the bulk nitride results in a lower solubility limit approaching within about 1 pct value of the true equilibrium solubility. Since the growth of the precipitate can be regulated by nitrogen input, the method offers certain unique advantages as a tool for studies of precipitation phenomena.

The following thermodynamic properties of the system have been determined in the range of 750 to 1200°C.

1. The solubility and heat of solution of nitrogen in alpha and in gamma iron are in agreement with results of earlier investigations.
2. The effect of vanadium on the solubility and activity coefficient of nitrogen in alpha and in gamma iron.
3. The equilibrium constant, free energy, and heat of formation of vanadium nitride (VN) from dissolved vanadium and gaseous nitrogen.
4. The solubility product for vanadium nitride in equilibrium with dissolved vanadium and dissolved nitrogen.
5. The solubility and excess free energy of the initial precipitates of vanadium nitride compound to that of the same substance in bulk.
6. An approximate value for the size of the initial precipitate.

Application of the data obtained to strain-aging phenomena in vanadium-bearing rimmed steels is discussed.

Mechanism of Age Hardening in Magnesium-Zinc Alloys: L. Sturkey and J. B. Clark, The Dow Chemical Co.

Magnesium-zinc alloys in the composition range from 4 to 8 pct Zn age-harden appreciably at temperatures between 200°F and 400°F after suitable solution treatment. A study of the mechanism of hardening has been undertaken using optical and electron microscopy, and X-ray and electron diffraction. No discontinuous precipitation occurs at the grain boundaries. The hardening is apparently produced by a general continuous precipitation, the particles of which are not clearly resolvable in the electron microscope until the alloys are overaged.

Electron diffraction studies of the precipitate in Mg-5 pct Zn single crystals show that the initial precipitate is not the equilibrium compound MgZn, but a transition precipitate MgZn′ the structure of which is indistinguishable from that of $MgZn_2$ (hexagonal, $a = 5.26$A, $c = 8.60$A.) This transition precipitate forms with one a-axis parallel to the c-axis of magnesium solid solution matrix, and the diffraction patterns show extensive *reiplanes* perpendicular to the matrix c-axis. These *reiplanes* correspond to rod-like ordered precipitation zones perpendicular to the matrix basal planes, and the hardening may be attributed to the obstruction of dislocation movement along the basal planes by these rods. As aging progresses, the ordered precipitate regions become larger, but even after 1000 hr at 500°F streaking confined to star-shaped reciprocal lattice regions persists.

Traces only of the transition structure MgZn′ can be seen in X-ray powder diagrams of the aged alloys. However, if the composition Mg_3Zn_3 is heated at temperatures below 450°F so that the eutectoid decomposition occurs, the X-ray powder patterns show that the Mg_3Zn_3 first transforms to magnesium solid solution plus the transition structure MgZn′, with coherency between the two structures. Further heating produces the equilibrium MgZn compound.

Precipitation Processes in Copper-Rich Copper-Iron Alloys: Alvin Boltax, Nuclear Metals, Inc.

Effects of several types of heat treatment on the magnetic and electrical properties and microstructure of copper-rich copper-iron alloys have been studied. The initial slope of the electrical resistivity versus atomic per cent curve for solution-treated and quenched alloys is 10.5 μohm cm per at pct Fe. On cooling alloys from 1050°C two distinct stages in the precipitation process are detected. The precipitation reaction between 1050 and 800°C results in the presence at room temperature of coarse equiaxed ferromagnetic particles. Upon cooling from 800°C to room temperature, precipitation continues with the formation of fine non-ferromagnetic coherent particles. A simple mechanism based on the Cu-Fe equilibrium diagram is offered as an explanation of this phenomenon.

The kinetics of precipitation during aging of solution treated alloys between 100 and 800°C were studied by means of electrical resistivity measurements. A monotonic decrease in electrical resistivity is observed during aging between 100 and 700°C. Using experimentally determined values of electrical resistivity versus per cent iron in solid solution as a correlation between the electrical resistivity and the fraction transformed, the time exponent in the rate equation of about ¼ and an activation energy of about 37 Kcal per mole are determined graphically. The reaction kinetics described are due to the precipitation of a non-ferromagnetic precipitate from supersaturated solid solution.

WEDNESDAY, FEBRUARY 19, AM

STRUCTURAL PROPERTIES OF METALS AND ALLOYS (II)

9:00 am — Ballroom (24th Floor)

Sheraton-McAlpin Hotel

G. M. Pound and C. G. Dunn, Associate Chairmen

Metallographic Observation of Rare Earth Metals: C. G. Kirkpatrick and V. F. Novy, Research Chemicals, Inc.

The rare earths (elements 57-72), scandium and yttrium, have long been a challenge to chemists and physicists. These elements, chemically quite similar, had resisted efforts to separate them economically prior to the development of ion-exchange. These recent developments in separation techniques have made available larger quantities of purified materials. High-purity metals prepared from these compounds have shown surprising differences in chemical, physical, and mechanical properties.

The authors' efforts have been directed to the development of techniques for the metallographic examination of these metals. Methods for grinding and polishing in organic solvents such as kerosene, diethylene glycol, mineral oil, etc., are discussed. The effect of various etches on the different rare earth metals is shown.

Some of these metals, notably cerium, oxidizes rapidly enough to allow a series of photomicrographs showing the method by which the oxidation proceeds. Other metals in the pure state, however, remain quite stable in air at room temperature. A wide variety of etchants, therefore, is employed, from air in the case of cerium metal, to dilute inorganic acids in the case of the more corrosion resistant rare earth metals. The effect of various etchants is also shown for metals of different purities.

On the basis of this study, it becomes evident that the rare earth metals require an extremely wide variation in the techniques that must be employed for their metallographic observation. This emphasizes again some of the differences in a series of metals once thought to be identical in all their properties.

X-Ray Analysis of Deformed Germanium, Gallium Antimonide, and Indium Antimonide: C. Kolm, E. P. Warekois, and S. A. Kulin, Lincoln Laboratory, Massachusetts Institute of Technology.

Measurements were made of the diffracted X-ray peaks of 99 pct reduced germanium, filed gallium antimonide and filed indium antimonide. In each case the material was worked at a temperature above its brittle ductile transition in order to insure plastic deformation. An analysis of the line positions of these deformed materials did not indicate the presence of stacking faults within the detection limit of one in approximately every 350 double layers. These results are in conformity with considerations of the energetics.

A Fourier analysis of the (111), (220), (440), and (444) peak shapes showed a small particle-size effect together with a pure strain distortion. The strains sustained by these materials were found to be several times smaller than those in similarly deformed metals and did not vary appreciably with averaging distance. This is in contrast to the non-uniform strains observed in metals studied by the same techniques and is consistent with widely spaced strain centers as evidenced by the size of the coherently diffracting domains, which varied from 400 to 2000 A. A small strain anisotropy was found in agreement with the anisotropic

Young's moduli in these materials. The strains in the <110> direction were approximately the same in the three materials, whereas the strains in the <111> direction could be related to the covalent bond energy.

Selective Revealing of Screw Component Dislocations by Low-Energy Cathodic Sputtering: B. Meckel and R. A. Swalin, University of Minnesota.

Using basically the technique of cathodic sputtering described by Wehner[1], the surfaces of several germanium crystals were bombarded by low-energy argon ions. The main feature of the technique used is the low kinetic energy of impinging gas ions as compared to usual methods. At a critically controlled current density and ion energy hillocks were observed to have formed relative to the surface in spite of the fact that the general level of surface was lowered by sputtering of crystal. Under high magnification, it was observed that hillocks characteristically terminated as plateaus at their summits. Clearly seen on the plateaus are the single and multiple spirals characteristic of screw component dislocations as well as double loops denoting Frank-Read sources.

In a germanium crystal studied, about 10^5 screw dislocations per sq cm were found on a (100) plane perpendicular to the growth direction of the crystal and a marked reduction was observed on a (100) plane of the same crystal oriented parallel to the growth direction.

Some Observations on the Recrystallization of a Silicon-Iron Crystal: Hsun Hu, Westinghouse Electric Corp.

Observations were made on the recrystallization of a 70 pct cold rolled silicon-iron crystal with an initial orientation of (113) [$\bar{3}32$]. Polygonization was found to be predominant upon annealing the deformed crystal at a low temperature, except in the regions near the edges, where recrystallization took place very rapidly. Within the polygonized matrix recrystallizaion nuclei were not entirely absent, but most of them failed to grow even upon subsequent annealings at much higher temperatures. It was found that complete recrystallization in such a specimen was always achieved by the selective growth of the recrystallized grains formed near the edges. When the recrystallization in the edge regions was completely prevented by etching-off large amounts of the material near the edges prior to annealing, the specimen remained unrecrystallized even after high-temperature anneals. Simultaneous recrystallization in both the edge regions and the central portion of the specimen could be obtained only when the specimen was annealed at a sufficiently high temperature with a rapid heating rate. These findings are in accord with the conclusions made from a previous study on the annealing textures in cross-rolled high-purity iron.

The orientations of all those successfully grown grains were found to be related to the polygonized matrix by <110> rotations of 20° to 40°. This indicates that growth selectivity is the governing factor in the formation of an annealing texture. Evidence was also furnished, which suggests that the difference in the recrystallization tendency is a result of the difference in lattice strain rather than the difference in orientation of the deformation texture.

Theoretical Interpretation of Metallurgical Effects Produced by Vibrational Treatments: M. C. Huffstutler, Jr., Texas Western College.

Results of a number of recent studies dealing with the effects of sonic and ultrasonic vibrations upon solidification and diffusion processes in metals have been considered from a fundamental viewpoint. While the dendrite-fracture theory may apply to high-intensity treatment of certain melts, he pronounced refinement of primary grain structure produced by low-intensity vibration treatments suggests the operation of other processes. The major grain refinement of freezing metals and alloys is probably due to agglomeration of sub-critical-sized nuclei in the melt. Even the mild agitation associated with stirring has been noted to produce such agglomeration in certain liquid systems. This explanation is compatible with all the experimental data. The possible effects of sound waves upon the rate of nucleation in liquid metals are discussed and other proposed mechanisms are evaluated thermodynamically. The processes of cavitation and degassing of liquid metals are interpreted in terms of the Fruth hole theory of liquids. The effects of the dilational coefficient of viscosity upon the rate of gas removal are discussed. Some of the experiments designed to evaluate the effect of ultrasound upon solid-state processes in metals do not distinguish between the effect of the vibration treatment on surface chemical reactions and the effect on place exchange processes (volume diffusion). The rate of place exchange in metals is probably not greatly enhanced by vibrational treatment. The literature relating to the effect of ultrasound upon solid-state diffusion and transformation processes is critically reviewed.

Redistribution of a Second Phase During Annealing in a Temperature Gradient: Paul Shewmon, Westinghouse Electric Corp.

If a two-phase alloy is annealed in a temperature gradient, there is a tendency for the piece to be enriched in one phase at the hot end. For example, Fe_3C concentrates at the hot end of α-Fe, while the hydride concentrates at the cold end of α-Zr. There are two effects that contribute to the flux in these cases. The first is due to the concentration gradient, which in this case is determined by the variation of solubility with temperature. The second is due to thermal diffusion effects, i.e., the contribution to the flux which arises from a temperature gradient in a single-phase alloy, and which is here superimposed on that resulting from the concentration gradient.

For the case where diffusion occurs predominantly in one of the two phases, equations can easily be derived for estimating the kinetics of the redistribution. It is concluded that for interstitial solutes the effect can be observed under conditions of time, temperature, and temperature gradient easily obtained in the laboratory. However, for substitutional solutes, the redistribution of the second phase will occur in a reasonable time only under conditions of very high temperature and temperature gradient.

As an example, the redistribution of Fe_3C in α-Fe will be shown and discussed.

WEDNESDAY, FEBRUARY 19, AM

GENERAL METALLURGY (I)

9:00 am — Winter Garden (24th Floor)

Sheraton-McAlpin Hotel

O. T. Marzke and J. J. Harwood, Associate Chairmen

Determination of Tests for Hydrogen Embrittlement of Titanium Alloys: R. R. Kennedy, Crane Co.

The mechanical properties of two commercial alloys, Ti-8 Mn and Ti-4 Al-4 Mn, were investigated in the as-received, helium-annealed, vacuum-annealed, and 150, 225, and 300 ppm hydrogen conditions. The Ti-8 Mn alloy in the form of 1/16 in. sheet and the Ti-4 Al-4 Mn alloy in the form of 1/2 in. round bar were each ordered from three vendors to represent the range of interstitial content found in present production.

Slow room-temperature notched and unnotched tensile and tensile stress rupture tests up to 1000 hrs were performed on both alloys. Slow room temperature notched and unnotched torsion, bend, and bend stress-rupture tests up to 1000 hrs were made on Ti-4 Al-4 Mn alloy. None of the unnotched specimens in any of these tests failed in a brittle manner. The notched tensile stress-rupture tests showed that the stress required for fracture at a given time slightly decreased with increasing hydrogen content. In contrast, the notched bend stress-rupture tests showed an increase in stress required for fracture.

Longitudinal and transverse tear tests at 80, 32, and −40°F were made on the Ti-8 Mn alloy sheet in the vacuum annealed and 300 ppm hydrogen condition. No apparent relationship was found between tear test failures and hydrogen content. Pin shear tests on Ti-4 Al-4 Mn alloy specimens containing similar quantities of hydrogen failed with ductile fractures.

Room temperature unnotched slow tensile tests on prestrained and aged specimens showed good ductility in both alloys. Specimens in the vacuum annealed and 300 ppm hydrogen condition were prestrained 5 pct in tension at room temperature and aged at 500°F for 24 to 48 hrs prior to test.

Comparison of results in this investigation with earlier work on hydrogenized specimens of these titanium alloys indicates that brittle fractures would have been expected in both alloys when tested in stress rupture at the 300 ppm hydrogen level.

Solute Gradient Melting: J. M. Lommel, General Electric Co., and Bruce Chalmers, Harvard University.

Solute gradient melting is the isothermal process by which a solid transfers into a liquid metal solvent until the compositions of solid and liquid have reached their equilibrium values, C_s and C_L, respectively. The process has been broken into two consecutive steps: the transfer of atoms from solid to liquid, and the diffusion of solute atoms through a boundary layer in the liquid.

A mathematical model was set up for mass transfer based on the diffusion of solute in stirred and unstirred liquids. The problem was made tractable for the case of stirring by assuming mass transfer occurred by diffusion through a boundary layer of constant thickness. To predict the rate of mass transfer when it was controlled by the rate at which atoms left the solid, a kinetic theory of melting and freezing was adapted to this problem.

The transfer of solid lead into liquid lead-tin alloys was investigated. When the liquid was not stirred, the data followed a liquid diffusion controlled model of mass transfer. The diffusion coefficient calculated from the data agreed with independent values, and the activation energy had a reasonable value for liquid diffusion.

When the liquid was stirred at high speeds the rate of mass transfer was independent of stirring speed, the solid was etched, and there was a grain size effect, indicative of a reaction controlled by the rate atoms go from solid to liquid. The activation energy for the process, 2 ± 1 kilocalories per mole, agreed with the predicted value, but there was serious discrepancy between the predicted and actual rate of reaction. It was shown that diffusion of tin atoms into the solid bringing the composition near the interface to C_s was not a necessary condition for solute gradient melting.

Solid Solubilities of Iron and Nickel in Beryllium: S. H. Gelles, Nuclear Metals, Inc., R. E. Ogilvie, Massachusetts Inst. of Tech. and A. R. Kaufmann, Nuclear Metals, Inc.

The solid solubility limits of iron in beryllium were determined between 850°C and 1200°C by analysis of differential type multiphase diffusion couples, using an X-ray absorption technique. The maximum value of the solubility limit was found to be 0.92 ± 0.02 at. pct (5.46 wt pct) at the eutectic temperature 1225°C. The solubilities of nickel in beryllium were determined between 900°C and 1200°C by the same technique and the maximum solubility was found to be 4.93 ± 0.01 at. pct (25.2 wt pct) at the eutectoid temperature, 1065°C.

A high-temperature phase, which decomposes eutectoidally at 1065°C, was found to exist in the beryllium-nickel system at a composition of approximately 8 at. pct Ni (36 wt pct) by diffusion

couple analysis. No mention of this phase has been made in previous papers on the beryllium-nickel system, although its presence has been confirmed in this work by thermal analysis and metallographic analysis of the structure resulting from the eutectoid decomposition.

Nickel-Titanium-Carbon System: E. R. Stover, General Electric Co., and J. Wulff, Massachusetts Institute of Technology.

An 870°C isothermal section, the ternary solidus equilibria, and the solubility of titanium carbide and graphite in the nickel solid solution have been determined with quenched, arc-cast specimens. Each of the nickel-titanium binary phases forms two-phase fields with titanium carbide. Solution of carbon in Ti_2Ni increases the solidus temperature, the lattice parameter, and the microhardness. The effects of carbon solubility in $TiNi_3$ were much smaller, and no effects could be detected in TiNi. No solution of nickel in titanium carbide was found.

A quasi-binary eutectic occurs between titanium carbide and the nickel solid solution at 13 at. pct Ti, 4 at. pct C, and 1307°C. On either side of the quasi-binary, ternary eutectics occur with graphite, at 1270°C, and with $TiNi_3$, at 1295°C. The nickel-graphite eutectic temperature was found to be 1328°C, and the nickel-$TiNi_3$ eutectic temperature was confirmed at 1304°C.

The atomic per cent solubility in nickel of titanium carbide together with graphite was determined from the Curie points of quenched samples between 1260°C and 600°C. The nickel corner of the three-phase field occurs at 3.4 Ti and 2.6 C at 1260°C, 3.1 Ti and 1.2 C at 1000°C, and less than 2.0 Ti and 0.2 C at 600°C. Thus, the binder of a titanium carbide-nickel cermet must contain an excess of titanium, or some other carbide forming element, if graphite precipitation is to be avoided during the sintering process.

Silver-Zirconium System: J. O. Betterton, Jr., and D. S. Easton, Oak Ridge National Laboratory.

A detailed investigation was made of the phase diagram of silver-zirconium, particularly in the region of 0-36 at. pct Ag. The system was found to be characterized by two intermediate phases. Zr_2Ag and ZrAg, and a eutectoid reaction in which the beta zirconium solid solution decomposes into alpha zirconium and Zr_2Ag. It was found that impurities in the range 0.05 pct from the iodide-type zirconium were sufficient to introduce deviations from binary behavior, and that with partial removal of these impurities an increase in the alpha phase solid solubility limit from 0.1 to 1.1 at. pct Ag was observed.

Equilibrium Diagram of Indium-Zirconium in the Region 0-26 Atomic Per Cent In: J. O. Betterton, Jr., and W. K. Noyce, Oak Ridge National Laboratory.

An investigation was made of the indium-zirconium system in the region 0-26 at. pct In and 550 to 1300°C. The α/β phase boundaries from zirconium allotropic transition were observed to rise with indium additions in agreement with general effects of higher valent solutes in zirconium and titanium. The maximum solid solubility of indium in alpha zirconium was 10.1 at. pct at 1003°C, the temperature of the peritectoid reaction, $\beta + \gamma \rightleftharpoons \alpha$. The beta phase dissolved 16 at. pct In at 1300°C, the maximum temperature investigated. The first intermediate phase is gamma with a disordered face-centered cubic structure. This phase is homogeneous from 22.4 at. pct In to at least 26.1 at. pct In.

Antimony-Zirconium System in the Range 0-5 Atomic Per Cent Sb: J. O. Betterton, Jr., and W. M. Spicer, Oak Ridge National Laboratory.

The solubilities of antimony in the alpha and beta forms of zirconium were determined between 750 and 1300°C. The alpha phase forms by a peritectoid reaction and the $\alpha/(\alpha + \beta)$ and $\beta/(\alpha + \beta)$ phase boundaries rise in temperature with increasing antimony. Impurities in the 99.95 pct zirconium were sufficient to influence the phase boundaries and the variation reported is approximate. The restricted solid solubility of the terminal zirconium phases, which is especially characteristic of this system, is thought to result from the low free energy of the Zr_3Sb phase.

THURSDAY, FEBRUARY 20, AM

GENERAL METALLURGY (II)

9:00 am — Winter Garden (24th Floor)

Sheraton-McAlpin Hotel

F. H. Wilson and D. E. Trout, Associate Chairmen

Commercial Techniques for Obtaining Sound Titanium Castings: M. L. Torti, National Research Corp.

The researcher in titanium casting has long been plagued with porous castings, as well as mold materials that reacted with the molten titanium to produce rough, contaminated, casting surfaces. The purpose of this investigation was to determine the causes of porosity and to determine procedures for their elimination, as well as to evaluate various mold materials.

The principal causes of porosity in titanium castings were experimentally determined to be entrapped argon, magnesium chloride vapors, and gases released from the mold material. Various mold materials were investigated. Mold materials that will yield acceptable castings in both the permanent mold and the expendable split-mold types have been developed.

Completely sound castings are now being obtained by consumably melting in vacuum a once-melted titanium ingot and casting into an expendable graphite mold that has been fired at 1600°C either in a vacuum or a reducing atmosphere. These castings exhibit excellent physical properties and negligible surface contamination. Surface finish and dimensional accuracy commensurate with high-quality steel sand castings are obtained.

Effect of the Order-Disorder Reaction on the Magnetic Anisotropy and Magnetostriction of Single Crystals of the Ferromagnetic Aluminum Iron Alloys: R. C. Hall, Westinghouse Electric Corp.

An investigation was made of the effect of the order-disorder reaction on the magnetic anisotropy and magnetostriction of single crystals of the aluminum iron alloys near the Fe_3Al composition. The crystals were given two heat treatments involving cooling at two different rates (about 20 to 30°C per hr and 100°C per minute) through the order-disorder range. Spontaneous saturation magnetostriction was measured by the strain gauge technique. Anisotropy was determined from torque curves obtained from a torque magnetometer system.

The first anisotropy constant, on disordering, changed toward larger positive values for all compositions. On the other hand, the variation in spontaneous saturation magnetostriction with ordering depended on composition. For instance, on disordering, the saturation magnetostriction in the [100] crystallographic direction increased at compositions (aluminum contents) less that Fe_3Al and decreased a compositions greater than Fe_3Al. The reverse effect was found for magnetostriction in the [111] direction except for a composition near 30 atomic per cent aluminum. Little effect of the ordering reaction was observed on the magnetostriction in the [110] direction. The saturation polycrystalline magnetostriction, assuming a random distribution of crystal orientation, increased at compositions less than Fe_3Al and decreased at compositions greater than Fe_3Al as the crystals were disordered.

A Note on the Use of Aluminum for the Deoxidation of Palladium and Its Alloys: R. N. Rhoda and R. H. Atkinson, International Nickel Co. (TRANSACTIONS OF THE METALLURGICAL SOCIETY OF AIME, February, 1958).

An improved technique has been developed for the deoxidation of palladium with aluminum which is especially suitable for use in making small castings with an induction-melting and casting machine. The effect of various crucible linings on the efficiency of the residual deoxidizer and accompanying oxide film in protecting palladium against oxidation during re-melting has also been examined; the preferred crucible lining consists of zirconia cement.

Comparison of Arc Melting Conditions and Their Effects on Reactor-Grade Zirconium Alloy Ingots: J. H. Hart, Westinghouse Electric Corp.

An outline of the early techniques used to melt zirconium alloys at the U. S. Bureau of Mines Station shows that a single, atmosphere, consumable-electrode, arc-melt was later replaced by a double, consumable-electrode, arc-melt, the first melt under an inert atmosphere and the remelt under a dynamic vacuum. Current arc melting specifications and conditions are described and contrasted with the Bureau of Mines techniques.

From evaluation work obtained by splitting zirconium sponge blends and by melting the partial blends under different conditions of rate and vacuum, evidence is given concerning the amount of hydrogen and chlorine retained in the ingot. Specific levels of vacuum applied during melting are related to the amount of volatiles contained in the ingot. Melting rate calculations are given and contrasted to the melting conditions and to the amount of sponge blend volatiles. Power consumption rates are also related to the melting conditions. Data presented indicates a higher melting rate and a lower power consumption rate for vacuum melting than is required for melting conducted under an inert atmosphere. The level of volatiles in double vacuum-melted zirconium is significantly lower than in zirconium first melted in a vacuum and remelted in an inert atmosphere.

Vacuum-melted zirconium alloys are shown to contain fewer microstructural stringers and microporosity than atmosphere-melted zirconium alloys. A review of mechanical properties, corrosion test results and microstructural considerations are given to indicate the benefits to be obtained by vacuum melting.

Metallurgical Factors Affecting the Corrosion of Uranium-Base Alloys in High-Temperature Water: M. W. Burkart, R. D. Leggett, and R. A. Wolfe, Westinghouse Electric Corp.

The disintegration of uranium-base alloys upon exposure to high-temperature water results from the formation of a metastable uranium hydride as the continuous phase in the metal. The corrosion life of these alloys can be markedly increased by preventing or retarding the precipitation of the hydride or by rendering the precipitate in an innocuous form. This was accomplished by heat treatment, alloying, water additions, and the use of a zirconium cladding.

Short time homogenizing anneals at 1000°C and aging treatments for three weeks at 300 to 400°C caused the precipitation of impurity compounds which prevented formation of the hydride as

a continuous phase. The addition of 0.3-1 pct of Cr or Ti produced peritectoidal decomposition in the alloy to form spheroidal particles of alpha uranium, which act as sinks for hydrogen and thereby prevent precipitation of UH. Platinum alloying additions prevent atomic hydrogen from dissolving in the metal. The platinum probably is present in the oxide in the metallic state and acts as a hydrogen depolarizer in the recombination of atomic hydrogen to molecular hydrogen. Similarly, platinum or nickel additions to the water are plated out on the metal where they act as depolarizers. With an alloying addition of 4 pct platinum plus proper heat treatment, the corrosion life of a uranium alloy in 650°F water was increased from seven days to a life equivalent to that of stainless steel in water.

The use of a zirconium cladding containing artificial defect holes provided excellent corrosion protection. In this case the zirconium act as a getter for the hydrogen generated at the defect.

Use of Plastecene to Simulate Metal Flow in Tandem Extrusion: E. J. Rapperport and W. B. Nowak, Nuclear Metals, Inc.

Plastecene was successfully used to *mock-up* the plastic flow of metals in extrusion. The justification of this use is based on the following:

1. The true stress-true strain curve for plastecene in compression has a yield point and exhibits "strain hardening."
2. Experimentally, the macroscopic deformation of plastecene has been found to be similar to that of metals.

The primary advantages in using plastecene are: it deforms under small stresses; it is available in many colors; and the stiffness may easily be varied over a large range.

A glass-windowed extrusion press was constructed to enable direct visual observation of the interface deformation in tandem extrusions. Billets of plastecene were prepared and pushed through this press to obtain "problem" interfaces similar to those encountered in extruded nuclear reactor fuel elements. A brief survey of interface geometries is presented and illustrated with slides comparing sectioned fuel elements and their plastecene counterparts.

Motion Pictures of Interface Flow in Tandem Extrusions of Plastecene: W. B. Nowak and E. J. Rapperport, Nuclear Metals, Inc.

A motion picture is presented illustrating the flow characteristics of tandem (and clad tandem) extrusions and the formation of some *problem* interfaces.

In the order of appearance the components in the picture are:

1. The deformation of a rectangular grid on a homogeneous billet.
2. The deformation of a physical interface, initially plane, between two sections of about the same stiffness—illustrating "normal" flow in tandem extrusions.
3. The production of a plane interface in the extruded material.
4. The formation of the interface termed *Dogbone*.
5. The illustration of *Void Formation* or *Gapping*.
6. Illustration of the problem termed *Shift*.
7. The deformation termed *Slippage*.

The factors contributing to the formation of each of these interfaces are discussed as the film is shown.

A Systematic Investigation of Metal Tandem Extrusions: W. B. Nowak and E. J. Rapperport, Nuclear Metals, Inc., and W. Wegner, U. S. Navy.

Tandem extrusion, as developed for the fabrication of nuclear reactor fuel elements, presents a variety of special plastic-flow phenomena. These are associated with the deformation of physical interfaces between billet components.

A systematic, before-after investigation of the interface shapes was performed, using two-component lubricated billets of lead-antimony alloys. These were directly extruded at room temperature through a conical die. Controlled parameters were the extrusion ratio (area reduction), the shape of the pre-extruded interface, and the ratio of the extrusion constant of the first to that of the second component, where the extrusion constant = (extrusion pressure)/ln (area reduction). The original interfaces were either a transverse cross-sectional plane or one of various cones coaxial with the billet. As a measure of the shape of an extruded interface, the area was taken between the interface trace on an axial plane and the diameter drawn through the apex of the trace.

Trends are noted between the area measure and the controlled parameters. In general, the area increases as the ratio of extrusion constants increases (other parameters constant); however, many of the curves exhibit maxima. Within the general framework of the experimental conditions, it is possible to predict some specific features of the extruded interface for a given set of extrusion parameters.

Temperature Dependence of the Free Energy Difference Between B.C.C. and F.C.C. Iron: Larry Kaufman, Lincoln Laboratory, Massachusetts Institute of Technology.

In the past twenty years four different tables of values have been published[1-4] for the difference in free energy between α and γ iron, $\Delta F_{Fe^{\alpha \to \gamma}}$, as a function of temperature.[1-4] Unfortunately, there are large differences in the low-temperature values reported by different authors. These differences have been pointed out recently in a review article by Kaufman and Cohen.[5] The primary difficulty in evaluating $\Delta F_{Fe^{\alpha \to \gamma}}$ at low temperatures arises from the fact that γ iron is unstable below 910°C. Consequently, the thermodynamic properties of fcc iron cannot be directly measured below this temperature and various extrapolation schemes must be used to obtain the specific heat of this phase at low temperatures.

Recently, however, Normann and Scheil[6] have measured the difference in enthalpy between bcc and fcc iron-nickel alloys over a wide temperature and composition range. These measurements can be readily extrapolated to 0 pct Ni (i.e., pure iron) and represent the best values of $\Delta H_{Fe^{\alpha \to \gamma}}$ presently available.

By utilizing these results together with the directly measurable thermodynamic properties of iron, explicit equations were derived which relate $\Delta F_{Fe^{\alpha \to \gamma}}$ *and* $\Delta H_{Fe^{\alpha \to \gamma}}$ to temperature between 0°K and 1183°K.

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[1] C. H. Johannsen, *Arch. f.d. Eisenhüttenwesen*, 1937, vol. 11, p. 241.
[2] C. Zener, AIME *Trans.*, 1946, vol. 167, p. 513.
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Effect of Plastic Deformation on the Resistivity of Cu-Pd Alloys: Erik Klockholm and Barry Hyatt, Franklin Institute.

Wire specimens of Cu-Pd alloys (9 to 23 at. pct) were quenched from above the ordering temperatures. The resistivity of the alloys was measured at room temperature after the specimens were plastically deformed in tension. An anomalous decrease in resistivity with elongation occurred for all compositions. The magnitude of the decrease was smaller than that reported for Ag-Pd alloys. An X-ray diffraction investigation before and after deformation showed no unusual structural behavior.

Electron Probe Micro-Analysis of Sub-Micron Precipitates in Alloy Steels: R. M. Fisher, Edgar C. Bain Laboratory, U. S. Steel Corp.

It has been found possible to use extraction replica techniques in conjunction with electron probe microanalysis to determine relative concentrations of alloying elements in very fine carbides formed in steels during tempering and isothermal transformation. Collodion or carbon extraction replicas mounted on platinum sheet are similar in appearance to the original steel specimen (when examined in the optical viewing system of the microanalyzer). The volume of precipitate particles analyzed in this way can be as small as 0.1 cubic μ.

THURSDAY, FEBRUARY 20, AM

PROCESSING OF HIGH-TEMPERATURE ALLOYS

9:00 am — Ballroom (24th Floor)

Sheraton-McAlpin Hotel

N. J. Grant and M. Achter, Associate Chairmen

Historical Review of Melting and Casting of High-Temperature Alloys: F. S. Badger, Haynes Stellite Co., Div. Union Carbide Corp.

The turbo supercharger, since its introduction in 1918, was the proving ground for highly stressed high-temperature alloys until the end of World War II when the turbo-jet engine took over as the mechanism requiring alloys of optimum high temperature properties. Currently, missile requirements are setting the pace for the development of radically improved alloys and materials. At no time have the requirements of advanced designs been completely and adequately filled and the pressure for and tempo of improvement required is continually increasing. The development from spring steels, through valve steels to cobalt- and nickel-base alloys with their optimum operating temperatures, is described. The effect of improvements in melting practice and casting practice in making more reliable the properties of these so-called super alloys is related. The effect of impurities both undesirable and desirable is outlined. Today vacuum-refined and cast alloys low in impurity content and high in reactive elements, such as titanium and aluminum, have been achieved with close control of essential minor elements such as boron and zirconium.

A broad jump in operating temperatures has called into being alloys of the reactive elements titanium, molybdenum, columbium, and tungsten. This has necessitated radically different melting techniques based primarily on high vacuum and particularly consumable electrode melting already used to control non-metallic distribution in alloys high in reactive elements. Here, however, a previously important but not controlling factor becomes all important. Oxidation resistance at temperatures above 2000°F guides alloy development and great emphasis is placed on surface protection of alloys suitable in every respect save this one all important property. Refinements of the skull melting and consumable electrode melting are now the order of the day and electron bombardment melting appears as a promising method of obtaining the energy at the high rates necessary for melting metals and alloys with extremely high melting points.

Effects of Variations in Nitrogen and Manganese Content on the Structure and High-Temperature Properties of Cast X-40 Alloy: E. E. Fletcher and A. R. Elsea, Battelle Memorial Institute.

X-40 melting stock was vacuum melted to produce a base material with the minimum amount of gas and volatile trace elements in solution. Suitable additions to this material brought the composition into the desired range, and the resulting metal was cast in hot investment molds to obtain test coupons from which stress-rupture specimens were machined.

In studying the effects of variations in nitrogen content, two series of melts were made, each representing a range in nitrogen content. The lowest nitrogen contents gave a 100-hr rupture stress at 1500°F about equal to the reported value for this alloy. However, increases in nitrogen content progressively decreased the rupture strength, and at some nitrogen content in the range of 0.1 to 0.2 pct the minimum strength was reached. Further additions progressively increased the strength of the alloy, and at very high nitrogen contents (0.25 to 0.33 pct) the rupture strength exceeded the normally reported value. Nitrogen variations up to the amount required to produce the minimum stress-rupture properties resulted in no change in the microstructure. However, further increases in nitrogen resulted in the formation of increasing amounts of a lamellar, pearlitic-type structure at the grain boundaries, accompanied by progressive increases in rupture strength up to 2500 to 3500 psi with no loss in ductility. The two series of melts represented different melting stocks and exhibited the minimum stress-rupture properties at different nitrogen contents. This suggests that some trace element not removed by vacuum melting has a strong influence on the response of this alloy to variations in nitrogen content, and consequently, before an optimum nitrogen content can be defined for X-40 alloy, it will be necessary to identify and control this unknown trace element.

In a series of melts with manganese contents ranging from 0.6 to 3.2 pct, the material with the lowest manganese content had the highest 100-hr rupture strength at 1500°F. The manganese variations had no appreciable effect on the microstructure.

Application of Vacuum Melting to Investment Casting: J. A. Miller, Haynes Stellite Co., Div. Union Carbide Corp.

Investment casting has been used to produce parts of complex configuration from hard-to-work alloys for a number of years. In the past few years, vacuum-melting has been developed to provide improved properties and qualities in wrought alloys. Vacuum-melting and investment-casting processes have been combined to produce castings of superior quality.

High-temperature alloys are vacuum melted in large furnaces from high-purity, raw materials to form master heats. Vacuum melting of these master heats allows closer control of the chemical composition, particularly, the reactive elements. The amounts of dissolved gases, hydrogen, oxygen, and nitrogen in the alloy are reduced. Residual elements, which vaporize easily, are removed. Vacuum melting reduces the formation of oxides and nitrides in the master alloy, thus, improving its cleanliness. Portions of the master heat are remelted without further additions and are poured to produce castings.

The investment-casting process involves the use of disposable patterns, composite molds, and special remelting and casting techniques. Furnaces for investment casting in high vacuum have been constructed and are in every-day use. Good quality investment castings made in vacuum or with the melt shielded by an inert gas are obtained on a production basis.

Nickel-base, aluminum and titanium-bearing alloys and cobalt-base alloys have been vacuum melted and investment cast. The properties and qualities of the castings produced have been superior to those made from air-melted alloys. Castings are produced to close dimensional tolerances and no machining of air foil sections is necessary before use. The grain size of castings is more readily controlled when remelted and poured in a vacuum. Remelting and casting in vacuum or with a shield of inert gas protects the alloy from contamination and preserves the properties of the vacuum-melted master heat as well as producing uniformally clean, accurate as-cast surfaces.

Effects of Certain Processing Variables on Physical Properties of Several High-Temperature Alloys: P. E. Hamilton, E. L. Bolin, and R. E. Roth, Allison Div., General Motors Corp.

The continually increasing speed requirements in air travel and missile operation require stronger and stronger alloys for use at high temperatures. The improvement in physical properties of alloys by vacuum melting techniques and practices and by variation of heat-treat procedures has been the object of considerable study during the past few years. A great deal of time and effort has also been spent relative to studying the joining of materials for fabrication of components, and the resultant shrinkage or growth factors.

This paper presents data showing an appreciable improvement in physical properties of nickel-base casting alloys (GMR 235 and GMR 235D) as a result of vacuum melting and casting techniques, as well as the improvement of an austenitic, precipitation hardening alloy (A-286) by means of consutrode or consumable electrode remelting. The methods of successful joining (welding and brazing) of these alloys with other appropriate materials will be described as well as the resulting growth and shrinkage data that must be considered in the fabrication of materials of this type.

Fabrication of High-Temperature Materials by Slip Casting: L. M. Schifferli, Jr., Haynes Stellite Co., Div. Union Carbide Corp.

Slip casting is a process for making shapes which consists of dispersing a finely comminuted material in a fluid, casting these suspensions into absorbent molds, removing the molded shapes, drying and subsequently sintering to increase density and strength. Slip casting, as an applied art, has long been used to fabricate plastic, clay base, ceramic materials into a variety of large sized objects in everyday use. In the past two decades, slip casting techniques were successfully applied to non-plastic, non-clay base, ceramic oxides such as alumina and magnesia.

Only in the past decade have such high-temperature materials as metal-ceramic combinations, intermetallic compounds and refractory metals been fabricated by slip casting. Practical aspects of the process such as slip preparation in 125 lb batches, mold making, casting and sintering up to 3100°F as well as necessary equipment are emphasized. The significance of particle size, viscosity and pH for preparing good suspensions (slips) are briefly shown. Applications of the slip casting process for fabricating such diverse high-temperature materials as silicon nitride, molybdenum disilicide, tungsten, tungsten carbide and metal ceramic mixtures such as chromium-aluminum oxide and tungsten-chromium-aluminum oxide are shown. Comparisons with other fabricating methods such as fusion casting, cold pressing and sintering, hot pressing and extrusion show slip casting and sintering produces materials with comparable, and in some cases, superior mechanical properties. Densities up to 95 pct of the theoretical are obtained for most materials. Comparisons of the process capabilities of these various fabricating techniques show the overall versatility of the slip casting method. Closed end tubes ⅞-in. outside diameter, ⅛-in. wall, in lengths ranging from 12 to 42 in. are produced in quantity. More precise tolerances than can be obtained in rough castings can be obtained by turning, drilling, and grinding operations.

Mechanism of Beneficial Effects of Boron and Zirconium on Creep-Rupture Properties of a Complex Heat-Resistant Alloy: R. F. Decker and J. W. Freeman, University of Michigan.

Recent research revealed that a major effect of melting practice on creep-rupture properties of a 55 Ni-20 Cr-15 Co-4 Mo-3 Ti-3 Al alloy was through introduction of trace boron and zirconium to the alloy.

This research has been continued by a microstructural investigation to establish the mechanism of the pronounced benefits of boron and zirconium on creep-rupture properties of the alloy at 1600°F.

Materials with varying boron and zirconium content were exposed to creep conditions and then the microstructures were analyzed by optical and electron microscopy, electron diffraction, microfractography and hardness measurements. Particularly useful were interrupted creep tests which allowed comparisons of materials after equivalent exposures.

The mechanism of improvement of creep-rupture properties was found to be a pronounced stabilizing effect of boron and zirconium on the grain boundaries of the alloy. The alloy with low boron and zirconium was subject to rapid agglomeration of $M_{23}C_6$ and γ' in the grain boundaries, followed by depletion of γ' and intergranular micro-cracking at the grain boundaries transverse to applied stress. Brittle fracture then occurred by linking of microcracks. However, additions of zirconium, boron, and boron plus zirconium decreased this tendency in that order. In the absence of these elements extensive micro-cracking was found early in second-stage creep at relatively short time periods and fracture occurred prematurely with very little deformation. Proper amounts of boron plus zirconium delayed micro-cracking until after third-stage creep started so that creep-rupture life was greatly prolonged and ductility to fracture markedly increased.

No effect of the trace elements on the size, amount, and distribution of the intragranular γ' was detected. Accordingly the property effects were not found to result from a change in the intragranular γ' reaction.

An estimate of the generality and limitations of the mechanism is given.

THURSDAY, FEBRUARY 20, PM

WROUGHT ALLOYS

2:00 pm — Ballroom (24th Floor)

Sheraton-McAlpin Hotel

G. V. Smith and F. N. Darmara, Associate Chairmen

Relationship of High-Temperature Properties to Working Procedure: J. W. Freeman, University of Michigan.

Cold-Rolling Enhances Mechanical Properties: D. W. Schulz, Haynes Stellite Co., Div. Union Carbide Corp.

High-temperature resistant nickel- and cobalt-base alloys are produced in wrought form by hot-working techniques. Due to the inherent qualities of these alloys, special and costly techniques must be used to reduce the cast structure to a usuable wrought product. Specialized heat-treatments have been developed to impart unique properties to hot-worked material. By utilizing carbide and intermetallic compound precipitation reactions, desirable mechanical properties can be tailored into an alloy.

Although many desirable properties can be achieved by properly heat-treating hot-worked alloys, certain mechanical properties can be further improved by cold-working. Cold-working by pressing, drawing, rolling, and associated processes will increase the ultimate tensile strength, yield strength, and rupture lives (below the recrystallization temperature) of these alloys. These improvements are generally realized at the sacrifice of elongation and reduction of area. Data gathered on nickel-base and cobalt-base alloys indicate

that mechanical properties can be increased significantly by cold-working.

Although cold-working alone enhances many properties of these high-temperature alloys, additional mechanical properties can be imparted to the alloys by aging the cold-worked material. By properly heat-treating cold reduced alloys, room and elevated temperature properties can be increased beyond values obtained for cold reduced material alone. Alloys that can be hardened and strengthened by a precipitation reaction that would normally take extremely long heat-treating times can be aged with shorter heat-treating times due to accelerated reactions caused by increased energy in the system due to cold-reducing. Tests have shown that nickel-base alloys, for example, can be improved in tensile strength as much as 30 pct over their normal values by cold reducing and aging. Improvement in stress-rupture properties continues to a degree above the recrystallization temperature.

Cold-reduced and cold-reduced-and-aged high-temperature alloys are in ever-increasing demand for such applications as bearings in high-temperature applications, springs, structural members, and associated applications where good mechanical properties must be maintained under extremely adverse operating conditions.

Effect of Processing Variables on the Properties of Udimet 500: E. J. Vargo and G. J. Guarnieri, Thompson Products, Inc.

A laboratory study has been conducted to determine the influence on hot strength and ductility of the thermal treaments and deformation conditions which may be encountered in the fabrication of Udimet-500 turbine buckets. Charpy impact data indicate the effects on ductility of various quenching rates from the solution temperature and of various aging times and temperatures. Electron and optical microscope techniques are used to determine the resulting changes caused in the precipitation of the γ' and carbide phases. A close correlation is noted between the marked loss in ductility and the growth of a continuous grain-boundary network of γ' and possibly carbide precipitates.

The effect on stress-rupture life of varying degrees of cold work followed by different solution treatments have been correlated. Higher stress-rupture strengths are associated with lower degrees of reduction and higher solution temperatures. While such trends may be related to grain-size variations, it is believed that other variables such as γ' precipitation pattern are of equal or even greater importance.

Effect of Processing Variables on the Properties of M252: J. Luchok and R. Stuligross, General Electric Co., and D. S. Chambers, Vanadium-Alloys Steel Co.

The purpose of this paper is to present the relationships of processing variables on mechanical and physical properties of a nickel-base age-hardenable alloy, M252. The rupture life, rupture ductility and tensile ductility are shown to be influenced by the grain size of the solution treated material. The grain size of the solution treated material in turn is affected by the following:

1. *Boron Content*: material of varying boron content (0.000-0.002 pct) have been converted to $\frac{5}{8}$ in. round bar stock using standard conversion practices. Finishing temperatures for this phase of the investigation were 1850-1875°F.

2. *Finish Rolling Temperature*: material of three boron levels have been converted to $\frac{5}{8}$ in. round bar stock with varying finish rolling temperatures.

3. *Temperature of Solution Treatment*: the effect of solutioning temperature on the physical and mechanical properties of materials processed under conditions one and two above has been determined.

Statistical Evaluation of the Properties Obtained From Air and Vacuum Arc Melted W-545 Alloy: J. Bulina and J. T. Brown, Westinghouse Electric Corp.

Tensile and stress-rupture tests were performed on four heats of W-545 alloy. Two heats were air-induction melted and two were consumable-electrode vacuum-arc melted. Specimens from one heat of each process were taken from 30 lb laboratory prepared bar stock, and from one heat of each process from 1500 lb pilot plant ingots forged to pancake disc stock. Test specimens from all heats had similar chemical composition, heat treatment, and grain size.

On each of the heats the following tests were performed: four tensile tests at room temperature, four tensile tests at 1200°F, four stress-rupture tests at 1200°F and 80,000 psi (plain bar and notched bar), and four stress-rupture tests at 1300°F and 65,000 psi (plain bar and notched bar). The data obtained were statistically analyzed for mean values and standard deviation. These values were then used to evaluate the two melting methods for W-545 alloy, and to compare the laboratory material with the pilot plant production material.

In a final analysis a simple decision technique is used to evaluate quantitatively the processing variables, air induction melting vs. consumable electrode vacuum arc melting, from the properties obtained.

Effect of Rhenium on Fabrication and Ductility of Molybdenum: R. I. Jaffee and C. T. Sims, Battelle Memorial Institute.

Addition of 50 pct rhenium (35 at. pct) to molybdenum results in the development of remarkable hot plasticity and low-temperature ductility. The Mo-50Re alloy may be cold worked directly in the as-cast condition, although this is not a preferred method of fabrication. The arc-cast Mo-50Re alloy may be hot rolled or forged directly without prior extrusion. The ductile-to-brittle transition is below −300°F. Oxygen forms a complex molybdenum-rhenium oxide which has high dihedral angles at the grain boundaries, and also tends to enter the grain matrix. In arc-cast unalloyed molybdenum, very small amounts of oxide produce a phase with low dihedral angle, which requires deoxidation. In contrast the molybdenum-rhenium alloy will tolerate at least 500 ppm oxygen in the as-cast condition and still be capable of direct hot working. At low temperatures initial deformation appears to be by twinning, with flow by slip enering only in later stages. As a result, stresses for initial deformation are quite low compared to the maximum flow stress before necking occurs.

The oxide redistribution mechanism found for molybdenum-rhenium appears to apply to tungsten-rhenium, but the low-temperature twinning mechanism is much less operative. As a result, about 30 pct rhenium greatly aids the hot workability of tungsten but is of relatively little benefit in ductility at low temperature.

THURSDAY, FEBRUARY 20, PM

PHYSICAL METALLURGY OF COBALT

2:00 pm — Winter Garden (24th Floor), Sheraton-McAlpin Hotel

F. R. Morral and G. A. Fritzlen, Associate Chairmen

Development of Cobalt-Base Alloys: J. B. McAndrew, J. J. Rausch, and D. W. Levinson, Armour Research Foundation.

A research program is being undertaken, under sponsorship of the Navy Bureau of Aeronautics, with the objective of developing wrought cobalt-base alloys having improved high-temperature properties.

The program is based upon a concept of alloy design in which the properties of binary solid solutions are determined initially. The solid solutions displaying the most desired properties are then further evaluated and more complex alloys are designed, based on the compositions thus previously selected.

Cobalt *rondelles* of commercial purity were used as the base material. Twenty elements were investigated as binary additions.

Alloys were prepared as 250-g melts by inert-electrode arc melting. The ingots obtained in this manner were forged to ½ in. rounds, the forgeability of the alloys being used as one of the criteria for evaluation. Alloys that were successfully forged were subsequently subjected to room temperature and 1700°F tensile testing as well as 1700°F oxidation testing. Based on these initial screening tests, the systems Co-Be, Co-Nb, Co-Ti, Co-Ta, and Co-Cr were found to contain alloys which were judged to be worthy of further study. Alloys in these systems were prepared as larger melts and studied more extensively.

In addition to the alloy development work, the effect of cobalt purity and the scavenging effect produced by small additions of titanium, manganese, beryllium, cerium, and mischmetal have been studied.

Damping and Shear Modulus of Cobalt: R. E. Maringer and L. L. Marsh, Battelle Memorial Institute.

Some preliminary damping and shear modulus data are given for recrystallized 99.5 pct cobalt over the temperature range of from −196 to 875°C. Over those limits the shear modulus varies from 12.75×10^6 psi to 6.1×10^6 psi with discontinuities appearing between 275 and 350°C and at 450 and 460°C. The latter discontinuity is believed to be associated with the allotropic transformation. There are at least two damping maxima, at 140 and 300°C, the origins of which are unknown. Above about 400°C, the damping rises continuously, with the energy loss presumably being due to grain boundary relaxation. The nature of the experimental scatter in damping data below −100°C suggests that part of the energy loss in cobalt is due to the relaxation of internal strains resulting from anisotropic thermal expansion. Increasing the strength of an alternating (60 cps) magnetic field is shown to increase the damping and decrease the shear modulus of cobalt, suggesting that a further part of the damping loss is due to magnetoelastic hysteresis.

Properties of Zone-Refined and of Powder-Metallurgy Cobalt: F. R. Morral, C. T. Sims, and E. F. Adkins, Battelle Memorial Institute.

Physical and mechanical properties are given for floating-zone refined cobalt of 99.98 pct purity and for powder-metallurgy cobalt of 99.7 pct purity. Preparation of these materials, particularly of the zone-refined cobalt, is discussed. Lattice parameter, density calculated from the lattice parameter, microstructure, and room- and elevated-temperature hardness of the as-zoned-refined cobalt are given. The zone-refined metal was fabricated by rolling to strip and a portion heat-treated so that conversion to the hexagonal-close-packed condition was as complete as possible. Another portion was quenched to retain the face-centered-cubic structure. Hardness, tensile strength, and ductility were obtained for each type of material at room temperature. Density was measured by water immersion for the hexagonal-close-packed cobalt.

Room- and elevated-temperature mechanical properties of the powder-metallurgy-type cobalt are also presented. This metal was almost entirely hexagonal close-packed as determined by X-ray examination, but polarized light examination of the powder-metallurgy material show some face-centered-cubic structure. Short-time tensile properties of hot-rolled strip were found for room

temperature up to 700°C, and step-type and continuous creep properties at 500°C are given. Recrystallization behavior and density measured by water immersion are also reported. Wherever appropriate, the effect of the face-centered-cubic to hexagonal-close-packed transformation on these properties is discussed and comparisons are made with the available literature.

Influence of Cobalt on the Transformation of a Chromium-Alloyed Austenite: P. Nicolaides, D. Coutsouradis, and L. Habraken, Centre National de Recherches Metallurgiques, Belgium.

Previous work has shown that in plain carbon steels, cobalt increases the transformation rate of the austenite displacing thus the TTT curves towards diminishing times. These results have been confirmed by the authors in the case of a 0.4 pct C-1.3 pct Mn steel and also in low-alloy steels.

To study the influence of cobalt in a chromium alloyed austenite the authors determined the TTT curves of steels containing 0.1 pct C, 12.5 pct Cr, and up to 12 pct Co.

It is shown that for contents up to 5 pct, cobalt increases the incubation time, displaces to lower temperatures the knee of the curve and decreases the transformation rate. For contents above 5 pct, a decrease in the incubation time is observed, the transformation rate, however, decreases appreciably. An effect of cobalt was also observed on the rate of the carbide precipitation in relation to the ferrite formation.

The bainitic transformation appears, for all steels studied here, at low temperatures, and overlaps partially the martensitic one. Martensitic points, (M_s-M_f), are slightly lowered with increasing cobalt content. An attempt to interpretate the observed phenomena is given.

Precipitation Phenomena in Cobalt-Tantalum Alloys: M. Korchynsky and R. W. Fountain, Electro Metallurgical Co., Div. Union Carbide Corp.

The kinetics and morphology of precipitation from solid solution in 5, 10, and 15 pct tantalum-cobalt alloys have been investigated in the temperature range from 500 to 950°C. The effect of aging time (up to 1000 hr) on Vickers hardness and the concurrent changes in electrical resistivity have been measured. Analysis of these latter data indicated that the precipitation process cannot be described by a single kinetic law. This observation was substantiated by metallographic examinations; the changes in properties were found to depend on two modes of precipitation: (1) general precipitation, and (2) cellular precipitation, resulting in the formation of a lamellar aggregate. Both these structures are unstable and on prolonged aging tend to dissolve to be replaced by a Widmanstätten arrangement of the precipitated phase.

The effect of the increasing volume fraction of the relatively soft lamellar structure on the overall macro-hardness of the alloys has been evaluated from micro-hardness measurements. The kinetics of the cellular precipitation reaction was determined quantitatively by lineal analysis. The activation energy of this reaction was found to be slightly higher than that of self diffusion of cobalt.

Three new intermetallic phases in the cobalt-tantalum system have been identified by X-rays: (1) a metastable α Co_3Ta phase, an ordered fcc compound of the Cu_3Au type, (2) a stable β Co_3Ta phase of hexagonal structure, formed at about 975°C by a peritectoid reaction between cobalt solid solution and the $Co_{2.2}Ta_{0.8}$, the hexagonal Laves phase of the $MgNi_2$-type, and (3) β Co_2Ta, a hexagonal Laves phase of the $MgZn_2$-type, which transforms at elevated temperatures into Co_7Ta, the cubic modification of the Laves phases ($MgCu_2$-type).

Nonmetallic Dispersions in Cobalt: E. F. Adkins, C. T. Sims, and R. I. Jaffee, Battelle Memorial Institute.

The effect of oxide dispersions on the room and elevated temperature properties of pure cobalt was investigated. Alloys studied contained 0.1 to 10.0 vol pct additions of Al_2O_3, SiO_2, TiO_2, Cr_2O_3, or ZrO_2. Typical powder metallurgy techniques such as ball milling, pressing, and sintering were used in consolidation. Fabrication was done by hot rolling after preheating in air or hydrogen at 1000°C.

Room-temperature tensile and hardness properties are given for the cobalt-oxide alloys and compared with data for pure cobalt. Most of the alloys tested showed an improvement in yield strength but a decrease in ductility, except for those with Cr_2O_3. Cobalt-Cr_2O_3 alloys showed generally superior yield strengths, ultimate tensile strengths and ductility compared to pure cobalt. The hardness of all alloys tested was higher than for pure cobalt.

Additions of 1 to 5 pct Cr_2O_3 produced considerable improvement in tensile strength. Creep properties of alloys with Cr_2O_3, TiO_2, and ZrO_2 additions were studied at 500°C under a stress of 12,000 psi. All of these alloys showed greatly improved creep strength compared to pure cobalt, with Co-1Cr_2O_3 and Co-0.2TiO_2 the best. After 250 hr at 500°C and 12,000 psi, the total creep of these alloys was less than 5 pct of that of pure cobalt.

Oxide particle size was an important factor in dispersion strengthening. Alloys showing the highest room-temperature tensile properties and elevated-temperature creep resistance also contain the finest oxide dispersions. Those dispersions had an average particle size of about 1 μ.

Exploration of the Electrical Resistivity of Cobalt-Base Alloys: J. C. Stewart, J. G. Dunleavy, and A. M. Hall, Battelle Memorial Institute.

An exploratory investigation of the influence of alloying elements on the electrical resistivity and workability of cobalt alloys was conducted. The program was motivated by the greatly increased availability of cobalt as well as by its close periodic relationship to the more common base metals for electrical-resistance alloys, iron, and nickel.

An inert-atmosphere induction melting method was used to melt and solidify the cobalt alloys in situ, and electrical resistivity measurements were made on the alloys after fabrication to wire.

The selection of the elemental additions made to cobalt in this study was based on considerations of atomic size, valence, crystallographic compatibility and solid solubility. Binary, ternary, and other multicomponent combinations were investigated.

Of the binary alloys explored, the composition 60 Co-40 Mn was of the most immediate interest as a base for exploring more complex alloys because of its relatively high resistivity and good workability.

Ternary additions to this 60 Co-40 Mn composition, selected by the above criteria, were explored. The most effective resistance raising elemental additions per unit weight of addition were found to be aluminum, silicon, titanium, zirconium, columbium, copper, and chromium in that order. When the addition elements were evaluated on the basis of atomic per cent of addition, the order of their effectiveness agreed generally with the order predicted from valency, atomic diameter, and solubility considerations. On an atomic per cent basis the order of decreasing effectiveness was zirconium, titanium, silicon, copper, and chromium.

The electrical resistivities of many of the workable alloys prepared during the course of the investigation are of no great interest per se. However, several members of this family of alloys may have electrical properties of commercial interest. For example, one alloy containing approximately 57.3 Co, 38.2 Mn, 4 Al, and 0.5 Ti possessed a resistivity of 750.8 ohms per circular mil foot.

Phase Transformations in Titanium-Rich Alloys of Titanium and Cobalt: P. R. Swann and J. G. Parr, University of Alberta.

Quenched structures were studied in alloys containing up to 12.5 at. pct Co. The subsequent decomposition of a 10 at. pct Co retained—β phase alloy was investigated using metallographic and X-ray diffraction methods. Hardness measurements were also made during the decomposition process. Precipitation of Ti_2Co is by nucleation and growth; and an activation energy of 50,000 cals per mole was determined. The values of the coefficient n suggests that the precipitate is pearlitic at temperatures between 450°C and 475°C, and spheroidal between 500°C and 525°C.

Comparison of the Mechanical Properties and Oxidation Resistance of Two Nickel—and Two Cobalt-Base Heat-Resisting Alloys Melted in Vacuum and in Air or Argon: M. J. Stutzman and J. W. Cunningham, Westinghouse Electric Corp.

The objective of this research program was the investigation of the potentialities for improvement of the mechanical properties at elevated temperature of heat-resisting alloys by varied practices of melting and investment casting. Two cobalt- and two nickel-base alloys were prepared under the following casting conditions:

Haynes Stellite 31 was melted and investment cast in air and in vacuum plus an argon atmosphere for pouring.

He 1049 was melted and investment cast in air and in vacuum plus an argon atmosphere for pouring.

Utimet 500 was melted and investment cast in vacuum with and without additions of zirconium and boron.

Guy's Alloy was melted and investment cast in vacuum and in argon.

The effects of melting and casting procedures upon the gas (hydrogen, oxygen, and nitrogen) contents, the tensile properties at room and elevated temperatures, the stress-rupture properties in the range of 1350° to 1800°F, and the oxidation resistance to air at constant temperature of 2000°F and intermittent exposure to air at room temperature and 2000°F were studied.

The data obtained on this program failed to support general conclusions applicable to the four alloys under investigation. Tests of specimens of one alloy failed to substantiate data obtained from other tests for related properties. The data must be evaluated for each alloy with close correlation to service conditions for design applications.

Some Portions of the Quaternary System Fe-Cr-C-Co: P. Nicolaides, D. Coutsouradis, and L. Habraken, Centre National de Recherches Metallurgiques, Belgium.

The effect of cobalt additions up to 10 pct has been studied in their ternary system Fe-Cr-C, by establishment of sections corresponding to 0.06 pct and 0.2 pct C. For each carbon content, chromium contents were 9, 13, 17, and 17 pct which correspond to those of steels that are extensively used in practice.

The determination of the *solidus-liquidus* transformation lines were carried out by thermal analysis in a high frequency induction furnace especially developed for this purpose.

The diagrams have been established in a practical scope so that for the elaboration of the alloys industrial products have been used.

The different phases occurring during transformation in the solid state were determined by means of various techniques: metallography, X-rays, extraction of precipitates, etc.

In a general way cobalt influences but little the liquidus and solidus curves. Cobalt exhibits an effect of broadening the gamma phase region which becomes more pronounced as the chromium content increases.

by E. W. Voice and R. Wild

HOW THEORY CAN HELP MAKE MORE SINTER

For several years the British Iron and Steel Research Association has been investigating the fundamentals of the sintering process. While all of the problems have not been solved, the separation of the various phenomena which occur during sintering has enabled a much clearer picture of the process to be obtained.

EARLY in 1954 BISRA, the British Iron and Steel Research Association, commenced an investigation of the fundamentals of the sintering process. The main feature of this work was an attempt to eliminate non-essential problems and to study separately the essential sintering phenomena. Inert materials were used in place of iron ores; the problems connected with water evaporation and carbonate decomposition were studied by incorporating widely varying proportions of these in the mix. Heat transfer down the bed was studied separately from combustion, and the inter-relation between the two was studied by making drastic changes in the nature of the fuel and the oxygen content of the sintering atmosphere.

Experimental Procedure

Sintering techniques: The results of sintering trials on a 2-ft sq experimental sinter box[1] and the successful use of a small scale laboratory sintering unit[2] suggested that a 3-in. diam sinter pot was a suitable size for this investigation. Closely graded materials (normally 1/16 to 1/8 in.) were used, and this allowed a normal sintering air flow (120 cfm per sq ft) to be used and normal bed permeabilities (70 to 150 BPU)[3] to be obtained.

Fig. 1 shows the layout of the experimental set-up. The raw mix is tumbled in a rotating drum to ensure complete mixing. A hearth layer ½-in. thick is first loaded on to the grate, and then the raw mix charged by hand to the desired depth. Bed thermocouples and suction probes are inserted as required during filling.

Ignition was effected by means of a slotted refractory block, preheated to 1300°C. This was placed in position with its lower surface ⅛ in. above the bed top, and the air flow was started and adjusted to the desired volume, normally 6 cfm. After ignition, the block was removed and the air flow reset to the desired value. From then onwards the suction was maintained constant until the peak waste gas temperature had been reached. Air flow, suction, waste gas temperature, and temperatures and suctions at various points in the bed were recorded as desired throughout the experiment.

In order to study the effect of changing oxygen content of the sintering atmosphere, known mixtures of oxygen, nitrogen, and air were supplied to the sinter pot from cylinders via a tightly fitting hood with the system adjusted to maintain the atmosphere above the bed at a small positive pressure.

Heat flow techniques: In the initial series of experiments a bed of inert material, without coke or water, was loaded in the normal manner with thermocouples in position. A quantity of the same inert material as that in the bed, equivalent to a ⅞-in. thick layer, was preheated to 1300°C and then poured on to the top of the bed and smoothed into a uniform layer. The fan was then started and the experiment carried out in the same manner as the sintering experiments. In experiments where special gases were used the apparatus was modified to allow the gas to be recirculated.

Experimental Results

Temperature distribution during sintering: Fig. 2a and b show the manner in which the temperature rises and falls at various levels down beds of silica chips and dense hematite particles. This type of temperature distribution is common to all beds, but the rate of rise and fall and the time at which the changes occur vary considerably. From such data it is possible to determine the temperature distribution down the bed at any instant, and Fig. 3 shows

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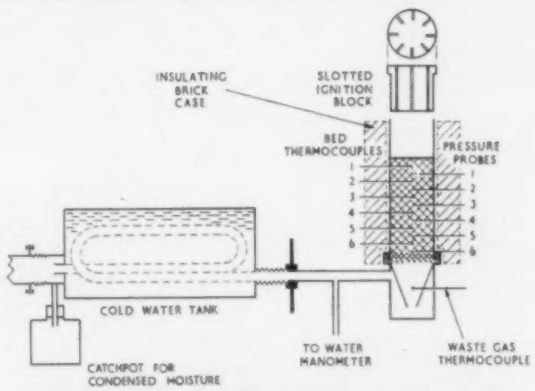

Fig. 1—Layout of the experimental set-up used by the British Iron and Steel Research Association to study the fundamentals of sintering.

this for a number of mixes when combustion is occurring approximately half way down. The flame front is clearly the level at which combustion commences, and for practical purposes either the 600° or the 1000°C contours has been taken to define it.

Fig. 4 shows the flame front travel through beds of silica, mullite, alumina, and alumino-silicate brick, and Table I shows the flame front speeds together with the bulk densities of the mixes and the average air flow during sintering. Values obtained using a dense hematite ore are also included.

Specific air and water gas volumes: The total volumes of air supplied and of waste gas evolved up to the time of peak waste gas temperature have been found for all experiments, and from these the specific air and waste gas volumes (cu ft of gas per ton of raw mix) have been calculated. These are shown in Table II. It can be seen that they are of the same order for all materials.

The highly porous nature of the alumino-silicate brick used enables mixes to be made up with widely varying moisture contents. Table III shows the manner in which the specific air and waste gas volumes increase with increasing water content in the mix. Mixtures of alumino-silicate brick and calcium carbonate (marble) have been used. Fig. 3 shows that it is possible to obtain the normal sintering temperature distribution down the bed with as much as 67 pct marble in the mix but not when the bed consists entirely of marble.

Fuel requirements for sintering: The fuel requirements needed to give normal temperature distribution down the bed for mixes with widely differing water and carbonate contents are shown in Table IV together with the net thermal requirement which can be seen to be relatively constant. This term has been obtained by subtracting the heat needed for endothermic reactions from the heat input from the coke and dividing the resultant figure by the weight of residual solid.

Heat flow experiments without combustion: Fig. 5 shows the rise and fall in bed and waste gas temperatures in the hot layer experiments using a bed of silica. The dotted lines show the rise and fall in temperature when silica is sintered. Comparison of the dotted and continuous curves shows the close relationship between rate of heat transfer and sintering. Whilst it is not possible, because of the more gradual temperature rise, to define precisely a *heat front* analogous to the *flame front*, it seems reasonable to consider the heat front as the level at which the temperature first commences to rise uniformly. In practice this is taken as the level of the 100°C isotherm. The heat front travel can be plotted on this assumption and is shown in Fig. 6 for the inert materials used. Table V shows the close relationship between heat front speeds and the flame front speeds.

Table V also shows the specific air volumes required in the heat flow experiments compared with the specific air volumes for sintering the same materials, both of which are based on peak waste gas temperatures.

The rise and fall of bed and waste gas temperature when gases of varying density and heat capacity are used is shown in Fig. 7a, and b, whilst Table VI shows the heat speeds and specific gas volumes for these experiments together with the densities and heat capacities of the gases employed.

It was not possible to use the hot layer technique when studying the heat flow through beds containing water and carbonate, as the heat available was insufficient; thus, the heat flow experiments were carried out using a permanent source of hot gases. Fig. 8 shows the influence of a small (5 pct) addition of water to a bed of silica on the bed tem-

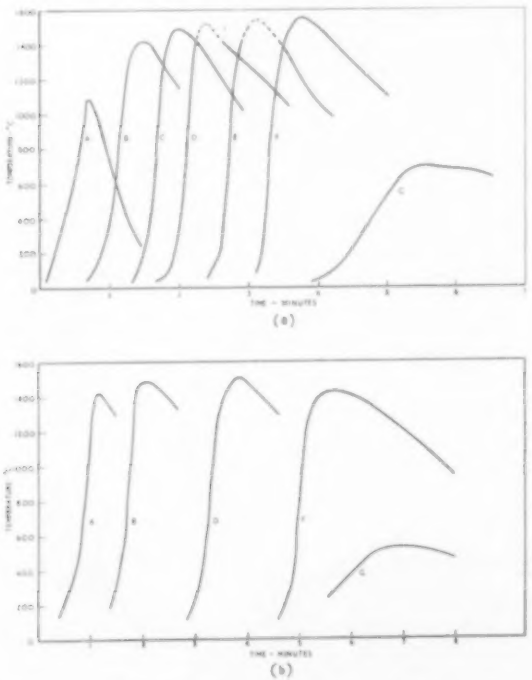

Fig. 2—Rise and fall of temperature at each level of sintering bed: A is ½ in. from surface, B is 1½ in., C is 2½, D is 3½, E is 4½, F is 5½, and G is the waste gas temperature. Diagram (a) is for a mixture of silica with 4½ pct coke and 3 pct H_2O. Diagram (b) is for dense hematite ore plus 3¾ pct coke, and 3 pct H_2O.

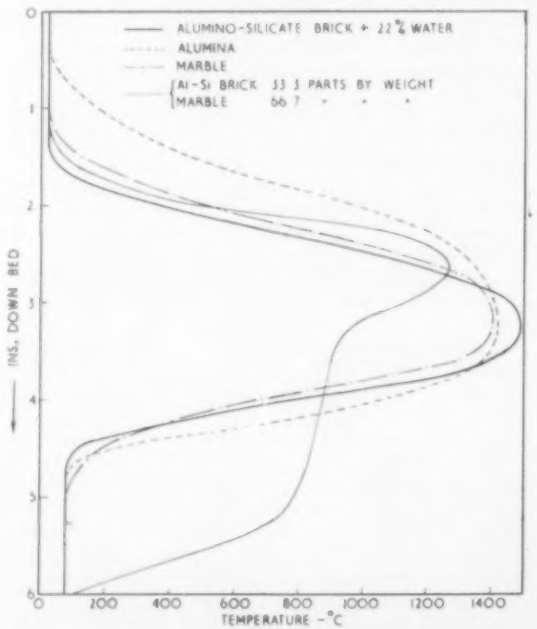

Fig. 3—Temperature distribution for different sinter mixes when combustion is occurring approximately half way down the bed. The flame front—the level at which combustion commences—is clearly visible.

peratures at various levels when air at 600°C is supplied to the top of the bed. Fig. 9 shows the effect upon the rate of rise of bed temperature of a large addition of water (33 pct) to a bed of alumino-silicate brick.

Sintering with various fuels and atmospheres: The specific air volumes for sintering a bed of silica with either normal coke breeze or titanium powder are shown in Table VII. This table also shows the bed temperatures reached and the volumes of air required for the combustion of each fuel.

Atmospheres containing four different oxygen contents were used for sintering a silica mix containing fuels of differing reactivities: wood charcoal (critical air blast value 0.003),[4] graphitized electrode carbon (critical air blast value 0.092), and normal coke breeze (critical air blast value 0.07). The first two of these fuels were crushed, screened, and mixed so that their size grading was the same as that of the normal coke breeze, and 4 pct (carbon content equal to 4½ pct coke) of each was used for sintering. Table VIII summarizes the information obtained in this series of experiments.

Fuel reactivity can be modified by changing the size grading; so, experiments were carried out using the standard coke in three different sizes namely +22 − 6, +100 − 22, and −100 mesh. In order to avoid differences of behavior consequent upon differences in quality of the different size fractions, the +22 mesh fraction of the coke was used throughout, crushed and graded when necessary. The highest bed temperature (1600°C) was reached with the medium sized fuel and the lowest (1420°C) with the −100 mesh fuel.

This experimental technique has also been used to study the influence of preheated air and to find the optimum conditions for sulfur removal. Full details of the results obtained and their relevance to plant problems will be published in *Blast Furnace, Coke Oven & Raw Materials, 1957 Proceedings* by AIME.

Discussion of Results

The separation of the various phenomena which occur during sintering has enabled a much clearer picture of the sintering process to be obtained. The extreme importance of heat transfer has become apparent and the inter-relationship between air flow, heat transfer, and combustion has been shown to control such important factors as specific air volume, fuel requirement, and the influence of preheated air.

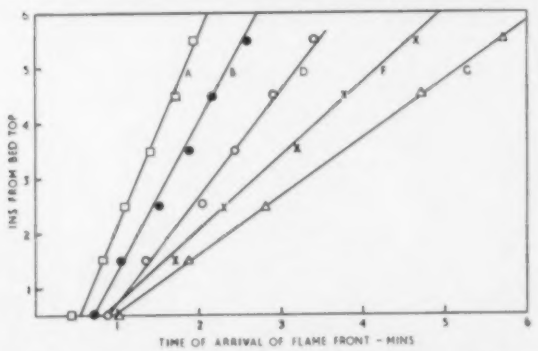

Fig. 4—Travel of the flame front through various materials. Square is alumino-silicate brick, 9 pct moisture, and 5 pct coke. Solid-circle is alumino-silicate brick, 40 pct moisture, and 10 pct coke. Open-circle is silica, 3 pct moisture, and 4½ pct coke. "X" is mullite, 3 pct moisture, and 5 pct coke. Open-triangle is alumina, 3 pct moisture, and 5 pct coke.

Specific air and waste gas volumes: The specific air volume must be determined by three factors: the mean air flow, the rate of travel of the combustion zone through the bed, i.e. the flame front speed, and the bulk density of the mix. Table I shows that these factors vary in such a manner as to produce a constant specific air volume. The derived constants in Table I may be compared with the values of the specific air volume in Table II where it can be seen that, whilst there is an appreciable range for each material, the values are all of the same order.

The specific waste gas volume will include the volume of water vapor and carbon dioxide given off by the mix during sintering. The value of this will, thus, be governed by the quantity of water and carbonate contained in a mix as well as by the factors already mentioned. When the water and carbonate contents are small, the specific waste gas volume will not be markedly different from the specific air volume (Table II).

When large quantities of water and carbonate are present, both specific air and specific waste gas volumes increase, the latter to a much greater extent. With beds of marble it is not possible to complete calcination in advance of the flame front (Fig. 3); thus, combustion is delayed, giving rise to a broader combustion zone and an increased specific air volume. Increasing the coke content of the mix accentuates this effect, since extra coke means more carbon dioxide in the gases leaving the combustion zone and thus a slowing down of calcination. When mixtures of inert material and carbonate are sintered, it is possible to obtain normal temperature distribution down the bed (Fig. 3) even when two parts of carbonate are used with one part of inert material, provided the correct coke content is used.

Fig. 5 shows that there is a remarkable similarity in the rate of hot zone travel whether or not combustion is taking place. Table V shows the close relationship between the heat front and flame front speeds and between the specific air volumes required for heat flow and sintering. Thus, it is clear that to transfer heat through a bed containing 1 long ton of broken solids about 30,000 cu ft of air is required, the weight of which is approximately the same as that of the solids. Since air and the solid materials used have approximately the same specific heats per unit weight, this equality of weights of gas and solid means equality of heat capacities, and experiments using carbon dioxide, argon, and helium show that the factor governing the volume

Table I. Flame Front Speed, Bulk Density, and Mean Air Flow of Sinter Mixtures

Mixture	Flame Front Speed, In. per Min A	Bulk Density, Lb per Cu Ft B	Mean Air Flow, Cu Ft per Min C	C / AB
Alumina + 5 pct coke, water 3 pct*	1.0	108	5	0.046
Mullite + 5 pct coke, water 3 pct	1.3	82	5	0.047
Silica + 4½ pct coke, water 3 pct	1.9	63	5	0.042
Alumino-silicate brick + 5 pct coke, water 9 pct	3.3	43	6¼	0.044
Dense hematite ore + 3¾ pct coke, water 3 pct	1.2	110	5½	0.042

* The water content, throughout this paper, is expressed as a percentage of the total sinter mix including water.

Table II. Specific Air Volume and Specific Waste Gas Volume of Sinter Mixtures

Material	Water, Pct	Coke, Pct	Specific Air Volume, Thousand Cu Ft per Long Ton	Specific Waste Gas Volume, Thousand Cu Ft per Long Ton
Silica	1½ to 5	4 to 5	34 to 44	35 to 46
Mullite	1½ to 7	4½ to 5½	27 to 44	28 to 45
Alumina	1½ to 3	5 to 6	32 to 40	33 to 41
Alumino-silicate brick	9	5 to 6	40 to 41	43 to 46

Table III. Variation of Specific Air and Waste Gas Volume with Water and Calcium Carbonate Content of Mixture

Alumino-Silicate Brick, Pct	Marble, Pct	Coke, Pct	Water, Pct	Specific Air Volume, Thousand Cu Ft per Long Ton	Specific Waste Gas Volume, Thousand Cu Ft per Long Ton
100	—	5 to 6	9	40 to 41	43 to 46
100	—	7 to 9	22	43 to 54	52 to 65
100	—	8 to 10	32	44 to 50	59 to 65
100	—	9 to 10	40	52 to 53	70 to 72
83	17	8 to 9	20	34 to 38	44 to 46
67	33	8 to 10	20	35 to 39	46 to 50
50	50	8 to 9	16	37 to 38	47 to 48
50	50	10	16	55 to 80	63 to 89
33	67	8½ to 9½	16	40 to 45	51 to 57
33	67	10	16	60	70
—	100	8 to 10	4	40 to 60	46 to 68
—	100	15 to 20	4	62 to 83	70 to 90

Table IV. Fuel Requirements for Normal Temperature Distribution

Material	Water, Pct	Coke, Pct	Net Thermal Requirement, Therms per Long Ton
Alumina	3	5	13.0
Mullite	3	5	13.0
Silica	3	4.5	11.7
Alumino-Silicate brick	9	5	11.3
	22	7.5	13.3
	33	9	12.5
	40	10.5	12.1
Al-Si brick 83 pct, Marble 17 pct	20	8.3	14.9
Al-Si brick 67 pct, Marble 33 pct	20	8.3	13.0
Al-Si brick 50 pct, Marble 50 pct	16	8.5	13.3
Al-Si brick 33 pct, Marble 67 pct	16	9.0	12.5

Table V. Heat and Flame Front Speeds and Specific Air Volumes

Substance	Heat Front Speed, In. per Min	Flame Front Speed, In. per Min	Specific Air Volume, Thousand Cu Ft per Long Ton: Heat Flow Experiments	Specific Air Volume, Thousand Cu Ft per Long Ton: Sintering Experiments
Alumina	1.1	1.0	34.7	32 to 40
Mullite	1.4	1.3	31.9	27 to 44
Silica	2.0	1.9	26 to 41	34 to 47
Alumino-silica brick	3.5	3.3	43.8	40 to 55

Table VI. Heat Flow through Silica Bed

	Gas: Density, Lb per Cu Ft	Gas: Heat Capacity, Mean 0° to 800°C, Cal per °C per Cu Ft	Heat Front Speed, In. per Min	Specific Gas Volume, Thousand Cu Ft per Long Ton	
		A		B	A x B
Air	0.076	9.5	2.0	38.1	3.43×10^5
Carbon dioxide	0.117	14.7	2.9	25.0	3.67×10^5
Argon	0.105	6.3	1.25	53.0	3.34×10^5
Helium	0.011	6.3	1.25	51.5	3.24×10^5

of gas necessary to transfer heat down the bed is indeed the heat capacity.

Confirmatory evidence that the specific air volume is controlled by heat transfer properties rather than combustion was supplied from experiments in which titanium was used as fuel for sintering a silica bed. Table VII shows that, although the combustion air for titanium was only about one third of that required when coke is used as fuel, the specific air volumes were virtually the same.

Small additions of water to the bed delay the initial rise in temperature at any level, but also increase the rate of rise above 100°C (Fig. 8). Large additions of water cause a very pronounced delay in the temperature rise above 100°C (Fig. 9), thus a considerable increase in the specific air volume, which, in the example shown in Fig. 9, is about 65,000 cu ft per long ton. These last experiments differ considerably from sintering experiments, but there is this common factor—the heat needed to evaporate the water and decompose the carbonates must be supplied by hot gases passing down the bed; thus, the presence of water and carbonate must delay the progress of the heat front to some extent.

In the sintering process the temperature in the combustion zone is about 1300° to 1500°C; thus, the heat content of the gas leaving this zone is high so

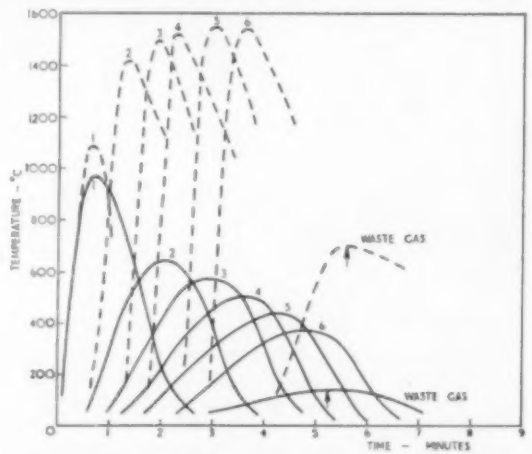

Fig. 5—Rise and fall of temperature at each level in bed during sintering (broken line) and heat flow (solid line) experiments on silica. One is ¼ in. from top of bed, two is 1¼ in., three is 2¼, four is 3¼, five is 4¼, and six is 5¼.

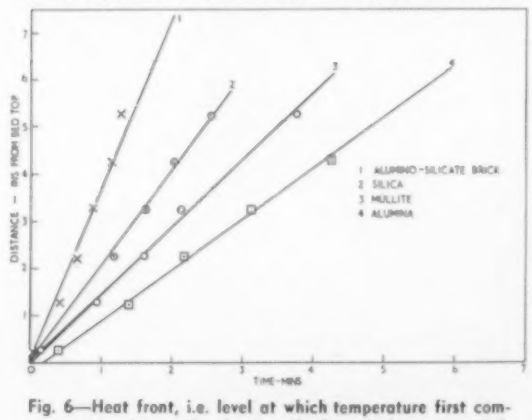

Fig. 6—Heat front, i.e. level at which temperature first commences to rise uniformly, travel through inert materials used in experiments.

that the delaying effect of endothermic reactions will be minimized. Lower down the bed, calcination liberates more gas at a relatively high temperature, which also carries heat down the bed. This carbon dioxide will be very effective as a heat transfer agent because of its high heat capacity per unit volume. Further down the bed, water evaporation takes place, but the effectiveness of steam as a heat transfer agent is limited by the relatively low temperature at which it is formed. Thus, both carbonate and water in a sinter bed will increase the specific air volume but the latter should have the greater influence. Examination of Table III shows that this is, in fact, the case. Increasing water content of beds of alumino-silicate brick from 9 to 40 pct increases specific air volume from about 40,000 cu ft per long ton to about 52,000 cu ft per long ton, whilst increasing carbonate content of the bed from 17 to 67 pct only increases specific air volume from the range of 34 to 38,000 cu ft per long ton to the 40 to 45,000 cu ft per long ton range.

Fuel requirements for sintering: The high temperatures which are reached during sintering are only possible because a hot zone travels through the bed and full use is made of heat recuperation between gases and solids. Thus, the fuel in the bed has to provide heat for endothermic reactions and heat up the solid material in the sintering zone to the requisite temperature. From Fig. 3 it can be seen that the thickness and temperature of the hot zone is substantially the same for all the inert materials used; the heat capacity of these materials will be proportional to the weight of material, since the specific heats are relatively constant. Heat losses will be approximately proportional to the duration of the experiment which will also be dependent upon the weight of material used. These considerations give a theoretical basis for the experimental fact that the *net thermal requirement* is reasonably constant for a wide range of sinter mixes. Since the precise numerical value will depend on the experimental conditions, particularly the size of the sinter unit and the bed depth, the value derived from laboratory experiments must not be taken as universally applicable.

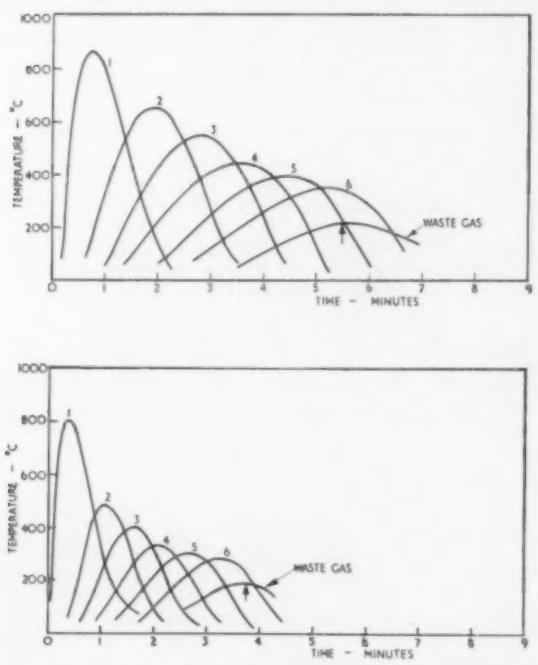

Fig. 7—Rise and fall of temperature at each level of the bed in heat flow experiments with various gases: top is air and bottom is carbon dioxide. Point one is ½ in. below surface, two is 1½ in., three is 2½, four is 3½, five is 4½, and six is 5½.

The relationship between heat transfer and combustion: These studies have established the important fact that there is a definite rate of travel of the hot zone down the bed independent of combustion. The heat generated in the top layers may arrive at a lower level in the bed at the same instant as combustion is taking place giving rise to an increase in the bed temperature, or it may arrive before or after combustion, in which case it will widen the high temperature zone without raising the temperature reached. These two experimental conditions have been designated *matching* and *mis-matching*, since the extent to which the heat front and flame front are co-incident is of extreme importance because it controls the temperature reached in the bed.

The agreement between the heat front and flame front speeds, shown in Table IV, strongly suggests that when normal coke breeze is used as fuel and air as sintering atmosphere, the first condition will be fulfilled and a narrow high temperature combustion zone will be obtained. The use of differing fuels and sintering atmospheres with differing oxygen contents will not materially affect the rate of heat transfer, but they will appreciably influence the rate of fuel combustion. Table VIII shows that an increased oxygen content in the sintering atmosphere and an increased fuel reactivity both increase the flame front speed, with a consequent broadening of the hot zone and a lowering of the bed temperature.

Relevance of findings to plant problems

At the outset of this BISRA research work in 1954 it was clear that a number of important questions could not be answered or could only be answered incompletely. Some of the more important of these are considered below. While it is not claimed that complete answers can now be given, the work described does go some way towards answering them.

Why does the optimum fuel requirement vary and how can it be assessed?

a) Endothermic and exothermic reactions vary with different ore mixes; these, however, can be allowed for quantitatively.

b) Different ore mixes will require different peak bed temperatures.

c) Different degrees of matching between heat and combustion fronts will give hot zones of differing widths.

d) Different ore mixes will give sinter cakes with different specific heats.

All these must be considered when estimating the fuel requirements and, as will be mentioned later, the correct balance between ignition heat and solid fuel must be found. Whilst it is not possible to give a simple formula for calculating optimum fuel requirements, the concept of *net thermal requirement* provides a basis for calculating changes which should be made when a different ore mix has to be sintered.

Do different materials require different specific air volumes? The specific air volume has been shown to be controlled by heat transfer requirements, and the results obtained suggest that a minimum value of around 25,000 cu ft per long ton is a likely figure. This, in fact, agrees closely with practice.[6] The function of the air in transferring heat downwards ahead of the combustion front makes it clear that increasing quantities of water in the mix leads to higher values of the specific air and waste gas volumes. It must be noted that, on commercial sinter plants, considerable leakage occurs at the pallet seals, etc.,[6] so that the amount of air actually going through the bed is usually only 50 pct of that drawn in at the fan. For this reason there is, for plant operation, an *apparent specific volume* based on windbox volume as well as the *true specific volume* passing through the bed.

How can the thickness of the combustion zone be varied? The combustion zone thickness depends on the extent to which the various fronts, which travel down a sinter bed, are in phase. First there is a water evaporation front, which if this does not keep ahead of the combustion zone, the bed will go out. Then there is the calcination front which, if it lags behind combustion, will cause a very marked broadening of this zone. Finally there are the heat fronts and combustion (or flame) fronts. The extent to which these travel down the bed together will largely determine the width of the combustion zone. A narrow combustion zone will give high fuel efficiency and minimize the problems of sinter cooling. Such a condition should be aimed at in normal iron ore sintering practice.

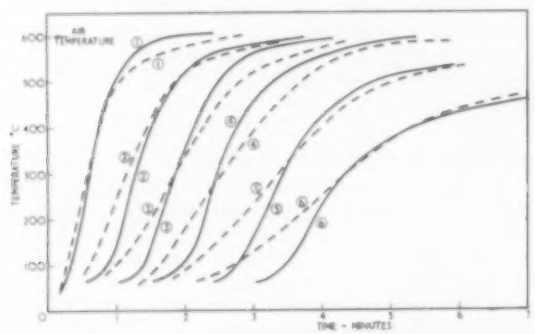

Fig. 8—Rise of bed temperatures with wet (solid line for 5 pct moisture) and dry (broken line) silica beds. Point one is ½ in. from bed surface, two is 1½ in., three is 2½, four is 3½, five is 4½, six is 5½.

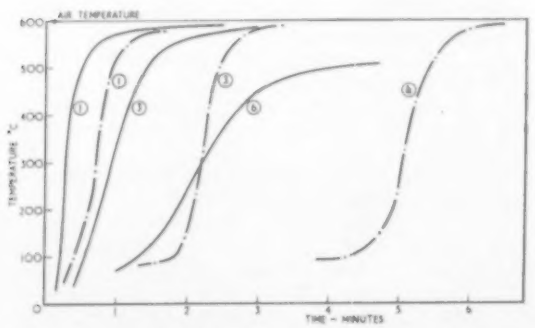

Fig. 9—Rise of bed temperatures for wet (broken line for 33 pct water) and dry (solid line) alumino-silicate brick beds. Point one is ½ in. from bed surface, three is 2½ in., and six is 5½.

Is coke breeze the best fuel and, if so, what is the optimum size grading? Studies of heat transfer and combustion rate strongly suggest that coke breeze is a very suitable fuel for commercial sintering. The optimum size of fuel must be chosen to give the best matching of combustion rate and heat transfer rate under the operating conditions. The experimental results indicate an optimum size between ⅛ in. and *dead fine*.

Why cannot the circulating load be drastically reduced? A high circulating load may be due to a number of factors, but the three following are the main causes: a) poor sintering technique, b) poor ignition, and c) excessive volatile loss from the ore. There would seem to be a good chance of decreasing circulating load by a) more attention to accurate fuel control, mixing, and loading, b) careful adjustment and control of ignition, and c) blending of mixes or other methods to avoid excessive evolution of volatiles during sintering.

Conclusions

The main findings may be summarized as follows:

1) Whilst the fuel requirements are related to the heat requirements of the process, the air requirements are much more dependent on the heat capacity of the sinter mix than on the oxygen requirement of the fuel.

2) A series of fronts travel down the bed during sintering — water evaporation, calcination, heat transfer, and combustion. The efficiency of the process depends on these fronts travelling down the bed correctly phased with respect to each other.

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Table VII. Specific Air Volume for Sintering Silica with Coke Breeze or Titanium Powder

Fuel	Fuel, Pct	Heat Release, Therms per Long Ton Raw Mix	Water, Pct	Peak Bed Temp °C	Specific Air Vol, Thousand Cu Ft per Long Ton	Air Needed for Combustion, Thousand Cu Ft per Long Ton
Coke	4 to 5	10.1 to 12.7	3	1600	33 to 41	10½ to 14
Titanium	6 to 7	10.2 to 11.9	3	1650	33 to 38	4½ to 5½

Table VIII. Summary of Information from Experiments on Sintering a Silica, 4 pct C, 3 pct H_2O Mixture with Different Fuels and Different Atmospheres

Fuel	Sintering Atmosphere, Pct O_2	Flame Front Speed, In. per Min	Peak Temp at Bottom of Bed, °C	Time above 80 pct of Peak Temp, Sec	Specific Waste Gas Volume, Thousand Cu Ft per Long Ton
Charcoal	100	7.8	1020	150	24.3
Charcoal	60	5.4	1240	105	24.8
Charcoal	21	3.1	1340	105	31.7
Charcoal	10	2.2	1340	87	40.4
Coke	100	4.0	1180	140	32.5
Coke	60	3.1	1200	110	31.5
Coke	21	1.9	1560	80	38.3
Coke	10	1.5	1200	100	57.0
Graphitized Electrode	100	2.4	1160	90	33.0
Graphitized Electrode	60	2.0	1190	85	45.5
Graphitized Electrode	21	1.8	1600	70	37.8
Graphitized Electrode	10	Bed went out			

by Edward A. Livingstone

The Atomic Age Challenge to Steel

Some months ago the submarine Nautilus was in dock for refueling. It had traveled 60,000 miles, but the total uranium used would make a lump smaller than a light bulb. This is only one example that the Atomic Age is here with us, now! How and where does this incredible Atomic Age challenge the first and greatest of America's basic industries?

OUTSIDE the field of atomic explosives, the major atomic effort being made in the Nation is to develop and use nuclear fission energy as a power source. This work is being carried forward on three fronts.

One front is military; the Army is developing mobile, self-contained power units fueled by uranium. The Air Force is working on nuclear-powered aircraft, and there is considerable talk about using atomic power for the propulsion of rockets and missiles. The Navy has a very active program in nuclear ship propulsion and has announced that it intends to power all its fighting ships by nuclear energy. It has been estimated that 75 to 100 reactors will be needed for Naval requirements in the next eight years.

Currently, the Navy has a total of 21 atomic-powered vessels built, building, or contracted for; this includes 19 submarines. The Navy program also includes a cruiser and the world's largest aircraft carrier. The carrier deserves a word or two of description. This ship will be an 85,000-ton giant to be propelled at 33 knots—about 40 mph—by an atomic power plant comprising eight reactors and 32 heat exchangers for steam generation to drive four screws.

The second front for nuclear power development is that of mercantile shipping. The first nuclear powered merchant ship to be built in this country—the NS Savannah—is scheduled for service by 1960.

The third front for nuclear power development lies in electrical utility power. Nuclear power for home, commercial, and industrial consumption represents a very large potential market indeed. The Nation's generating capacity has been rising by about 7 pct each year. It is obvious that in the foreseeable future there just isn't going to be enough gas, oil, and cheap coal to maintain this progression. Someone pointed out that if every American home had a central air conditioner—a not unreasonable prospect for the future—and they were all turned on at the same time, the power load would equal the nation's total generating capacity today. Nuclear power certainly appears to be the only future answer to the rising curve of kilowatt demand and the falling curve of reserves of fossil fuels. It is already the answer, now, for such countries as Japan, which has no fossil fuels, or England, whose reserves are highly depleted.

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The Atomic Energy Commission is conducting a Demonstration Power Reactor Program. In that program, a number of different types of reactors are being actively explored or developed through large-scale, pilot plant stage to determine advantages and disadvantages for electrical power.

The real challenges lie within the reaction zone

Reactor types differ mainly in the heart of the nuclear power process, that is, in the kind of and manner of fuel distribution, and in the cooling system for removing heat from the fuel. Externally, nuclear systems are much like any other plant. The tonnage structural components are made of steel. This includes heavy reactor and pressure vessels, radiation shields, and steel containment vessels about the entire unit to prevent biological dangers in case of leakage or other failure. The principal parts of the system include the fuel elements, the cooling system and heat exchange units, the control rods, and the structural parts within the reaction zone. Here materials requirements are more stringent. And herein lie the real challenges of the Atomic Age to Steel.

The principle of perfection

The foremost challenge—and one with which we can come readily to grips—is the demand of nuclear energy applications for products to be applied on the basis of the principle of perfection. This implies that the highest quality product is always used to insure maximum reliability against failure and against the biological hazards of radiation. Again, because of uncertainty about performance, quality, or corrosion resistance, extra components, such as intermediate heat exchangers, are built into the system. Certainly, it's over engineering—due solely to uncertainty about performance and the abilities of materials to resist reactor conditions, but at this stage errors must be on the side of safety. A failure could cause serious physical harm to many people. The psychological reaction could be so severe as to hinder or halt future development of this power source.

There have been problems with uncleanliness of component parts. For example, the program on an experimental homogeneous reactor was recently set back one year, because of stress corrosion cracking difficulties induced by chlorides carried into the system on a certain improperly cleaned stainless product.

Babcock & Wilcox is attempting to meet the reliability challenge in specialty stainless tubing by using special manufacturing and testing techniques calculated to produce tubular goods of superlative quality. For example, B&W is inspecting tubing in the finished state using both fluorescent penetrant and ultrasonic methods to supplement normal visual inspection. Finished tubes have been handled with cotton gloves with tube ends plugged to prevent contamination inside. Continued development will be necessary. Undoubtedly, our present inspection methods will be crude 10 years from now, and our quality then will be super-superlative.

Corrosion in reactor cooling systems

Another important challenge of the nuclear program lies in the corrosion involved in reactor cooling systems. Many of the power reactor types under investigation introduced distinct or unique corrosion conditions. The pressurized water system is one of these.

This is the type of reactor with which American industry has had the most experience. The Nautilus contains a pressurized water unit, and so does the Duquesne Light Station at Shippingport, Pa. The Con-Edison Station at Indian Head outside New York City and the merchant ship Savannah, described earlier, are also pressurized water units. A large share of the power reactors to be built in the next 10 years will be of this type.

In these units, high-purity water is circulated through the fuel elements at about 2000 psi to prevent boiling in the core of the reactor. This primary system water is heated to 525°F in the core and then passed to heat exchangers which function as steam generating units.

The high-purity, hot, water coolant is quite corrosive. Corrosion resistant steels are required for cladding the reactor vessel and for structural parts in contact with the water. This includes the heat exchangers for steam generation and the fuel elements which can be of tubular construction. At present, electric furnace stainless steels such as Types 304, 304L, and 348 are used for these purposes and satisfactorily resist general corrosion.

Nuclear engineers, however, feel some concern about these austenitic stainless steels because of their susceptibility to stress corrosion cracking. Conditions which cause stress corrosion cracking are present in these systems, particularly in the heat exchangers where chloride impurities may concentrate to high levels in the crevices between tube and tube sheet. Here, resistant stainless steels are definitely needed to eliminate cracking tendencies—the alternatives are other materials of construction or expensive purification systems to remove chloride which can never be foolproof.

We may be able to overcome the problem of stress corrosion cracking by use of a stainless alloy developed by B&W, Croloy 15-1. This alloy contains 15 pct Cr and 1 pct Ni. It is weldable and resistant to stress corrosion cracking with good general corrosion resistance as well. Another possibility lies in the use of vacuum-melted stainless steel of high purity with extremely low carbon and nitrogen. This is in the experimental stage.

There are corrosion problems in other types of reactor cooling systems. One potentially efficient system uses molten sodium for coolant. This is resisted by stainless steel, if the sodium is free from oxygen, but the stress corrosion cracking possibility pops up again in the steam generating system, particularly if there is any chance for sodium and water to mix to form sodium hydroxide. Difficulties with the sodium cooling system in the atomic submarine, Seawolf, together with the very heavy radiation shielding necessary to this highly radioactive system, led to decreased emphasis by the Navy.

In the homogeneous reactors, a reacting solution of uranyl sulfate and heavy water acts as fuel, moderator, and cooling system. It is circulated through heat exchangers to generate steam for power. The acid nature of the solution can cause corrosion problems. Special stainless steels are being developed for this service.

All the reactor types under investigation do not use stainless steels. Certain types, such as the liquid metal fueled reactor, which employs a molten bismuth-uranium fuel solution, may use electric-furnace alloy steel, such as Croloy 2¼. There is considerable impetus to developing the less corrosive reactor systems, such as the gas-cooled system, which uses carbon steel, because of corrosion hazards in other systems. Obviously, the need to develop more corrosion resistant materials for reactor systems is a pointed challenge of the Atomic Age. Imagine the problems involved in one reactor type now under development. This reactor uses plutonium in the molten state as fuel at temperatures over 2000°F, and plutonium is one of the most poisonous radioactive substances known.

Radiation damage

Another challenge lies in a highly technical zone. The nuclear chain reaction from atomic fission causes the discharge of great quantities of energy, and materials such as stainless fuel elements or structural members in or near the reacting zone are subject to intense bombardment from particles and radiation from fission. Compare the particle impingement to a very high speed rifle bullet on an atomic scale. It is inevitable that some damage will result on such impact. This particle bombardment of a material causes damage which is called *radiation damage*.

Tests on irradiated specimens indicate that steel is somewhat susceptible to these effects. This radiation effect on steel manifests itself in the form of increased hardness, tensile strength, and yield strength, and lowered ductility and impact resistance. Knowledge of the magnitude of these effects and their interpretation is urgently needed for reactor steels. Lack of knowledge tends to cause overdesign in order to compensate for the maximum credible possibility. This leads to very heavy shields to minimize any possible effects on structural components. It is possible that in the future we will need to design steel for resistance to radiation damage, or at least select and use the alloys which best resist these effects.

Induced radioactivity

Induced radioactivity is another totally new concept in steel applications. This involves radioactivity produced within the steel as a result of changes in the atoms of iron, alloy elements, or residual elements to radioactive isotopes. Certain of the common alloying elements in steel form isotopes which have intense or long lasting radioactivity. Chief among these are cobalt, manganese, and tantalum;

however, iron, chromium, and nickel also form radioactive products. Induced radioactivity presents tremendous difficulties in shielding, in maintenance work during shutdowns, and in disposing of corrosion products which circulate in the system and become radioactive. Highly corrosion-resistant steels are greatly to be desired for this reason as well as those already mentioned; thus, the great interest in stainless or super-stainless steels.

Neutron absorption cross-section

Neutron absorption cross-section is still another new aspect to the application of steels for nuclear systems. Absorption cross-section is a measure of the probability that an atom of an element will capture a neutron in its vicinity.

A large neutron absorption cross-section is undesirable for most reactor materials because neutrons are captured and kept from reacting. Neutron efficiency is lowered, which means that a larger quantity of the expensive fuel is needed to sustain the reaction. Of the elements in steel that are commonly added, manganese, tungsten, tantalum, cobalt, and particularly boron have high capture cross-sections. Boron is so potent that even almost imperceptible traces may exert a detrimental effect in fuel elements. On the other hand, boron in amounts of one to two percent is being added to stainless steels for use as control rods and for structural purposes such as neutron shields. Boron controls the reaction. In the shields, it catches neutrons and thus prevents radiation damage.

There may also be definite advantages in deliberately adding extremely small controlled amounts of boron to fuel element materials. This will provide a *burnable poison* of a high absorption cross-section to assist in control of the reaction. The *poison* will be gradually consumed at a rate roughly corresponding to the diminished activity as the uranium is used. This would seem to call for vacuum melting techniques of a high order of efficiency. Vacuum melting would be needed, not only for the addition and control of boron, but also for obtaining steels of high purity and controlled composition, maximum high temperature properties, and uniformity.

High temperature applications

Another challenge lies in the field of alloys for high temperature applications. The capability of nuclear reactions to produce high heat energy is enormous. For example, the temperature attainable in fission reactions is of the order of 20,000,000°F, while fusion of hydrogen isotopes, as in the H-bomb, produces temperatures in the vicinity of 200,000,000°F. In order for nuclear power to grow and become competitive with fossil fuels, greater thermal efficiency of reactor systems will be necessary. One improvement will come with increased reliability of structural materials which will permit elimination of intermediate systems. However, in the over-all development of nuclear energy, the availability of economical materials to withstand high temperature applications will be paramount.

The problems of tomorrow incomprehensible in the light of the knowledge of today

Consider the fusion reaction which involves joining of isotopes of hydrogen—a reaction which involves temperatures of about 200,000,000°F. Can we conceive of materials capable of withstanding a sufficiently useful fraction of this tremendous energy? Yet this reaction is being actively studied at the level of the basic physics of the process for power applications.

We know nothing about the materials requirements for fusion. From the nature of the reaction we can guess that materials involved will need to have great high temperature strength and resistance to hydrogen attack. We may have to study unusual engineering possibilities; we may have to develop alloys with low vapor pressures and with maximum atomic bonding to resist the chipping forces of high speed particle bombardment.

Summarizing the challenges

For the immediate future one challenge is that of understanding and placing the correct interpretation on the effects of radiation damage.

Another challenge lies in grasping and understanding the new concepts of steel applications in reactor systems. We cannot hide from unfamiliar terms, such as *neutron absorption cross-section* and *induced radioactivity*. We must prepare ourselves to understand and deal with these new concepts as they affect the use of steel.

We have the perennial challenges of the need for steels of greater high-temperature strength and greater corrosion resistance.

Many of the familiar high-strength alloying elements, such as cobalt and tungsten, have unfavorable neutron absorption or radiation characteristics.

Corrosion requirements are amplified by the need for maximum resistance. The hazards of corrosion failure are great. We need to prevent buildup of radioactive corrosion products within the system.

We, in the steel industry, have a challenge to our manufacturing techniques. We must produce even more reliable products in which perfection is far more than an aim. The development and exploitation of new methods, such as vacuum melting, must be continued at an accelerated pace. Development of new techniques for inspection must continue. We are far short of the ultimate.

Many problems already with us

We cannot take a lackadasical stand on these challenges; they are our problems. Atomic progress is moving at such a pace that many of these problems are already with us. Those I have tried to project for the more distant future may be here tomorrow.

The future of nuclear energy is itself a challenge. The development of this new industry is going to depend heavily on getting the materials necessary to do its job. The very future of our country depends on energy sources and hence eventually on nuclear fuels. The steel and steel fabricating industries have never been in a better position to meet the challenges. Steel has a magnificent new physical plant. It now has an impressive number of modern, well equipped research laboratories. It has the first rate people needed to do the work.

I am sure steel will be equal to the challenge of the Atomic Age, whether that challenge requires new solutions to old problems or calls for fresh approaches to new problems with new materials and new manufacturing techniques.

A Brief Summary of the Report on Evaluation of Engineering Education

Development of engineers who can face new and difficult engineering situations with imagination and competence invariably involves both professional and social responsibilities. The Committee considers that scientifically oriented engineering curricula are essential to achieve these ends and recommends the following:

1) A strengthening of work in the basic sciences;

2) The identification and inclusion of the six engineering sciences;

3) An integrated study of engineering systems, planned to stimulate creative and imaginative thinking;

4) The inclusion of elective subjects to develop special talents of individual students;

5) A concentrated effort to integrate work in the humanities into engineering programs;

6) Insistence upon a high level of performance in the communication of ideas;

7) The encouragement of experiments in education;

8) The strengthening of graduate programs necessary to supply the needs of the profession; and

9) Positive steps to insure the maintenance of faculties with the intellectual capacity as well as the professional and scholarly attainments necessary to implement the preceding recommendations.

THE "COMPLEAT" ENGINEER

There is a rising tide of opinion holding that manpower needs are not so much numbers as they are for an engineer **better prepared in every way** *for the age in which he will live. The report on which this article is based was started in 1952 and published in 1955; recent events have only added urgency to the opinions and ideas expressed.*

by George K. Dreher

THIS paper is an outgrowth of and is made necessary by the Report on Evaluation of Engineering Education,[1] referred to from now on as *the Report*.

[1] Report on Evaluation of Engineering Education, American Society of Engineering Education, 1955. Copies of this report are available from the ASEE, University of Illinois, Urbana, Ill., for 25¢. In lots of 50 to 100, the price is 20¢ and for 100 or more copies, the price is 12¢.

If this Report were clearly understood within industry, by the political forces that control the purse-strings of most of our universities, by high school faculties, by both present and prospective engineering students, and by engineering faculties themselves, there would be little need for discussion.

The Report sets forth a fundamental step in engineering education that had to come sooner or later. It represents a stage in engineering progress and a reversal of the trend developing from the practical early approach (dealing with the over-all problem of civil and military engineering), to the numerous engineering sub-divisions of the present. Somewhere a reversal in this trend was necessary or the end result would be a kind of man who could not survive outside of his own peculiar pre-selected engineering environment.

The problems associated with this Report are common to all new ideas and perhaps reflect errors

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of omission of which not only the committee, but also industry, government, universities, and we ourselves are frequently guilty. Primarily, there is a lack of broad public communication which permits misunderstanding to breed by itself.

Another omission involves control of the personal ambitions of a few engineering deans and professors who may seek to use the Report as a means of developing a curriculum pointed solely towards research and scientific personnel at the expense of many students who cannot achieve this level for one reason or another. This is not intended or implied by the Report, but rather that the engineering graduate emerge as a more completely equipped and better prepared individual.

Purpose of the Report

The Report Committee states that it was instructed by the ASEE in May of 1952 as follows:

> "The Committee on Evaluation was asked particularly to clarify the curriculum content that differentiates engineering education from that in science, on the one hand, or in sub-professional technology on the other."

If this statement is kept in mind by engineering administrators, professors, and faculty members, such questions as now prevail can readily resolve themselves. The Report further states:

> "The technical goal of engineering education is preparation for the performance of the functions of analysis and creative design, or of the functions of construction, production, or operation where full knowledge of the analysis and design of the structure, machine or process is essential. It also involves mastery of the fundamental scientific principles associated with any branch of engineering, including a knowledge of their limitations and other applications to particular problems, such as the development of materials, machines, or structures as well as the ability to make critical scientific and economic analysis and to organize these into clear, concise and convincing oral or written reports."

In that statement, and in other parts of the Report, it is acknowledged that the engineering function will be retained and that engineers will engage in analysis, design, production, and operation, as well as in the sales and executive fields. These functions industry can and is using in just that manner.

The Scientist Engineer

The engineer is conceded to be the man who has the ability to transfer scientific knowledge into useful human purposes; however, the effect of this Report upon too many people is to give the impression that engineers will be good only for research and science. Graduate study has and is creating the *Scientist Engineer*—and there is no reason why some should not bridge over into science and be better by reason of their engineering background. If a new function is needed, then let us acknowledge it and make the proper arrangements; however, let us be certain that means by which a proper understanding of such a move can be attained are included in the overall plan.

Professional ethics

The Report emphasizes the need for a deep sense of professional ethics and moral and ethical values consistent with the career of a professional engineer. The engineer, by the nature of his education and training, possesses a relatively high level of professional ethics and honesty.

Honesty will not be enough, however, as the engineers of the future will live in a more restrictive world than has been the case with many of us. Safety requirements have complicated the design of virtually every process and machine, and will be a growing challenge in the years ahead. The legal problems of product liability will require that he possess a very sound background and greater ability on which to base the design he creates for our future use.

. . . and the humanities

Much point has been made of the need for education in the humanities. It is to be hoped that such education will be of more help to this new engineering graduate as he hits the rough bumps of early industrial life. These courses, plus their integration into all engineering study, may create a frame of mind which will permit the young student to achieve those abilities that will make him likeable to his associates in industry. It includes a realization that he and such men as he directs must meet, or exceed, standards of cost, quality, quantity, and human service in order to become an economic asset to his firm or the agency which employs him. He needs diplomatic honesty in his reports and the ability to engage in interdepartmental cooperation, to acknowledge the ideas and achievements of others, to take their suggestions, to have a willing attitude, and to be satisfied only with good work, whether it be long hours of research or the scramble to achieve production goals and deadlines. It is certain that we can use men of that caliber, and that the humanities can help achieve these attitudes.

Such men cannot be created, however, under adverse conditions. The Report recognizes that the attitude of the university faculty is reflected in the student body. The committee points out the disregard of some past engineering professors for the humanities, and emphasizes that the goal which these courses seek to achieve cannot be reached under this kind of negative leadership. Neither can the goal of successful industrial internship be achieved if the faculty delights in taking industry apart at the seams. In both cases, the disservice is to the student more than to the industry, but in the end everyone is the loser.

The same can be said for the practice of ethics. If you will pardon a personal observation, I would like to mention a practice in both industry and college that I consider a violation. When a young man works on a thesis or does the actual preparation of an engineering paper, he should be acknowledged as the author or co-author. His superior in industry or in college is, in my opinion, guilty of robbing that young man of his mental creation if his work, or a revision thereof, is published under the former's name. Any student or young engineer would be proud to be co-author of such a paper, but complete burial is a certain method of discouraging any growing creative ability in a young mind.

Creativeness is nurtured by recognition. It seems to me that recognition is a strong facet of a proper *professional climate*, both on the campus and in industry. Concurrently, the measure of a professor should include recognition of the publishable papers

of his students instead of a total emphasis on the professor's sole efforts. The latter encourages an unethical and an inhuman practice. Again, it is the few, not the many, who are responsible for this defect—but the damage is out of proportion to their number.

The new curriculum

In several universities where the foundry industry, through the Foundry Educational Foundation, has offered scholarships, the new curriculum suggested by the Report has been in effect for several years. If we are to judge by the achievements of some of the young men who have entered the castings industry, then it can be honestly stated that the curriculum works in practice.

In the steel casting industry, these young men, under the guidance of our engineers, have proven to be able speakers and have contributed worthwhile technical papers. These papers have reached out and drawn ideas from the engineering sciences for application to our problems. As a total result, the steel castings industry has progressed further since World War II than it did in all of the years prior to that time, and we feel that this has merely scratched the surface as far as application of the engineering sciences to this industry is concerned.

Quoting again from the Report:

> "Other areas due for close scrutiny, with a view towards possible elimination or reduction in time, are those courses having a high vocational or skill content and those primarily attempting to convey engineering art or practice."

The casting industry recognized this goal as a desirable one in its early association with engineering colleges; even in 1950, many university casting laboratories were actually relics of the dim past. In talks before engineering groups and our own industry, we stated that in one summer's time we could teach an engineering student more about the practical and empirical side of foundry operations than he could learn in a college laboratory during the entire four years.

Engineering school casting laboratories, since World War II, were developed to demonstrate the use of the engineering sciences and to foster the wider use of research in the improvement of processes. More simply stated—the probable path of engineering education was in the wind, and we were guided into its course. Today, in these laboratories, there are opportunities to engage in analytical problems covering the six divisions of the engineering sciences advocated in the Report. In addition, most of them are in a position to demonstrate the actual functioning of engineering laws to all engineering students.

The "uncommon" man—why so uncommon?

For anyone who has ever worked in industry, the blessing of a few thinking men on the staff cannot be overstated. If it were possible to make analytical and creative thinking a habit, instead of an effort, not only our industry, but everyone would be extremely happy about such an accomplishment.

One of the weaknesses frequently noted in men is the inability to apply all they know to a given situation. An engineering graduate is needed who constantly seeks to interpret all operations and problems in terms of engineering principles—and to be so constituted that he would be mentally uneasy until he had thoroughly completed such an explanation in his own mind, to the end that his judgment would be based on sound knowledge rather than empirical or faulty experience.

This ability would also achieve another very worthwhile end. Frequently, when an engineer is incapable of mustering a thorough mental review of engineering principles in his mind, he will take off on a development or research project using the most expensive possible way. A little more thinking, and broader knowledge, will reveal a simpler and less expensive way to achieve the same result.

If a student can be imbued with a philosophy of self-education, our industry, at least, would be more content to have the man who has been taught to use proper thinking techniques, even if this were at the expense of some of the fundamentals. In any case, we live in the hope that the young engineer will realize there is much for him to learn. The Report is clear in revealing that college is only the beginning of an engineering education.

The science of measurement

The Report also gives emphasis to measurement:

> ". . . including analysis of accuracy, precision, and errors and the appreciation of the degree of accuracy economically justified, together with some understanding of statistical methods. . . ."

For some unknown reason, both industry and colleges have continued to make some basic errors in this area for several generations. Many of these are due to a lack of appreciation of the philosophy set forth in the above quotation. Measurement extends into test equipment, meters, gages, temperature and electrical controls, oscillographs, and many items, such as Geiger-counters and other instruments of the incoming age. With all of these devices there is a need for constant checking to see that the instrument is being used properly and is doing an accurate job of recording. No one can determine the amount of economic waste that occurs each day in industry merely because measurement is incorrect or is not being accurately interpreted or controlled. The concept of correct measurement is fundamental to engineering—but it is not instinctive.

Every university laboratory cannot possess all of the measuring, testing, and control devices which are used in industry. However, those devices which they do have on hand should be taught from the basis of the principle under which they are designed and under which they should be used. A very homely example concerns the use of a Rockwell hardness tester. A senior student was observed making a Rockwell hardness test at one end of an 18 in. bar, with the other end hanging unsupported in the air. The weight of such a bar is not only injurious to the machine, but introduces a force which aberrates its measurement. This is only one example—there are others even more gruesome. The proper understanding of even a few devices develops a mental technique that can guide a student throughout his life. It avoids the idea of *faulty experience* as a background for decision.

Speaking of measuring devices, there are other points that deserve consideration. One of these revolves around a need for a universal mechanical drawing and sketching technique in which symbols, references, and specifications have the same meaning no matter who makes the drawing. Most of the professional societies and the Mechanical Drawing Div. of the ASEE have been working towards this

Attention is called to the special Metallurgical Manpower Symposium, at this year's Annual Meeting in New York. To be held at 2 PM on February 16 in the Sheraton-McAlpin Hotel, the session will present the problem as it exists today, and a plan of action for the metallurgy and ceramics professions.

objective, but unified effort is needed to get results. It is a long road but misinterpretation of blueprints by engineers, technicians, and mechanics still remains a fundamental cause of economic waste, let alone the irritations and difficulties it engenders for the organizations affected. Mechanical drawing and sketching is, after all, a means of communication and is a language in itself which an engineer must be able to interpret; it needs uniformity.

Pursuant to this uniformity, the engineer should have a common reference point, plane, or set of planes in the part itself, from which all dimensions on a drawing will be made. This would mean that the pattern-maker, the lay-out man, the jig and fixture designer, the tool and die-maker, the gage-maker, the production engineer, and the inspector would all work from, and have their equipment so produced as to coincide with, these common points of reference and from pre-established locating points in the production sequence. The lack of this principle in our engineering work is another fundamental cause of waste and high blood pressure, not only between a customer and a supplier, but even within a plant that produces the entire unit.

Professional responsibility—who trains the graduate?

There is a rather deeply engrained idea that an engineer, when he graduates, is ready for full responsibility, in spite of the fact that this has not been the case for many years. The larger firms very readily and profitably assimilate the current and future engineering graduate. The smaller firms have had some difficulty and will have more in the future. This will be particularly true in those firms which are trying to progress but do not have an engineering staff or an engineer who is free to guide the development of a young man. This problem applies equally well to any company which falls into the truly small to medium category but, nevertheless, needs engineering ability on its staff.

In the small business scene, there is the general impression that the new engineering graduate will not be of much value, in view of the additional training he will require and the company's inability to provide it. The statement in the Report that small companies will seek these new graduates because they are more broadly educated seems not to be well founded.

In the castings industry, during the past 10 years, there has been a trend for smaller firms to persistently lure qualified men from their present jobs—and the same is generally true across the Nation in all industry. Many, but not all, of the smaller firms will, of necessity, have to pirate engineers in a more thoroughly organized manner from among those who are trained by larger companies and who have gained sufficient experience to operate on an independent basis in an engineering capacity —it is one of the problems of our times. Of course, pirating is not limited to the small firm alone, and there is a distinction between pirating and genuine opportunity.

The second-best student

Many engineering colleges have a curriculum set up so that a student who cannot quite make the grade as an engineer is able to go on to a degree course under some other designation. Graduates from such courses are of value. Experience indicates that the qualified engineer moves through an organization to a position of either executive or sub-executive capacity, but there are many other managerial tasks to be filled in supervision or the sub-engineering and plant functions which can be readily handled by graduates who are familiar with the engineering world. There is considerable human and economic waste in permitting a low survival rate to persist in the face of industry's growing need for the good, as well as the excellent man.

It is possible, too, that many universities will extend the technical institute idea from which students may branch into regular engineering or into which students, who cannot continue engineering education for any cause, could shift but still gain from the investment which he and his family have made in his future. The regular technical institutes outside of the university group should be integrated more thoroughly into the educational system so that some credits can be transferred back and forth. A student who cannot afford to attend a university beyond a year or so may readily afford a technical institute education in his home city or in some city where he has more of an opportunity to earn his way.

The whole man

The basic truth of the matter is really a simple one—the engineer must be better prepared for the age in which he will live. It is this idea that should be emphasized. We are looking forward to a better all-around man as the product of our engineering colleges. It is the whole man who determines success or failure. For him, education is a tool to be used along with his other qualities. A good man will adapt himself to his chosen field in a short time.

The Report Committee found an approach which is designed to bring out these qualities in men along with a better education. We can only hope that it will be applied with the same honesty with which it was written.

Let us not forget, however, that the successful defense of our country in World War II and the very evident human progress of the succeeding decade were conceived and consummated, in a large measure, by the engineers and scientists who were educated, trained, and who taught in the decades from 1900 to 1940. The present and coming generations must be better—whether or not they will be, many of us may never know.

Gradual depletion of high-grade Lake-Superior iron-ore deposits has directed attention to the beneficiation of marginal and low-grade ores. Beneficiation processes—either flotation or magnetic—must be followed by agglomeration to produce pellets of sufficient size for blast-furnace charging. Three distinct techniques have been developed for hardening such pellets; updraft traveling grate, downdraft traveling grate, and the shaft furnace. The development and operating characteristics of all three pellet-hardening methods are presented in this issue of Journal of Metals.

—The Editors

UPDRAFT PELLETIZING OF SPECULAR-HEMATITE CONCENTRATES

by Donald C. Violetta

LIMITATIONS of the sintering process as applied to the agglomeration of fine iron-ore concentrates are related directly to the sizes and aggregating properties of the ore particles. A normal sintering mixture is composed predominantly of material which ranges in size from ⅝ in. to 100 mesh, whereas concentrate is composed of material which ranges in size from 100 mesh to less than 10 μ. Unless the concentrate has high aggregating properties, it is quite impervious to a gas stream and, as such, inhibits the capacity and operability of the conventional sintering process.

Poor aggregating properties

Aggregating properties, in this case, may be defined as the ability to form small agglomerated fragments or accreated masses by a normal mixing action, and the ability to maintain these shapes during drying and firing. Coarse-screened ores are a natural aggregate, and fine, slimey ores have good aggregating properties. However, specular-hematite flotation concentrate has a very low tendency to aggregate, due to its particle sizes, shapes, and surface chemistry and, as such, is readily air borne in a gas stream when dry.

Reports from the Rouge plant[1] of Ford Motor Co., where Humboldt specular-hematite concentrate is used in the sinter mix, have shown that a good quality sinter could be produced at high tonnages with 30 pct of the ore mix as fine concentrate. An increase in the amount of concentrate usually resulted in higher vacuums, lower windbox temperatures, and reduced tonnages.

Sintering trials unsatisfactory

Laboratory studies at The Cleveland-Cliffs Iron Co.'s Research Laboratory have shown that sinter mixes containing 100 pct specular-hematite concentrate must be combined with at least 60 pct returns to produce good quality sinter, free from dust and unfired material. Batch sintering tests have shown this type of mixture would produce only 0.77 long tons per sq ft per day of +⅛ in. sintered material.

The aggregating properties of specular-hematite flotation concentrate may be increased with the addition of such binding agents as bentonite clay. However, with the addition of 0.5 pct bentonite to the concentrate, it required 50 pct returns to obtain a permeable bed and produce a favorable quality sinter. This addition of bentonite increased the capacity to only 1.01 long tons per sq ft per day of +⅛ in. sintered material. The addition of limestone to the ore mix did not increase the capacity of the sinter tests.

Shaft-furnace, little improvement

In view of the limitations of sintering as applied to specular-hematite concentrate, The Cleveland-Cliffs Iron Co. directed its research program toward pelletizing. After studying the pelletizing problem and having preliminary tests conducted at the University of Minnesota's Mines Experiment Station, Cleveland-Cliffs became directly interested in the shaft furnace as a method of agglomeration and constructed and operated a 1-ton per hr pilot plant. The plant was operated from 1950 through 1952 with favorable results obtained when pelletizing natural magnetite, but several operating difficulties were encountered when pelletizing specular-hematite concentrate. It was difficult to maintain a uniform combustion zone in the furnace, because all the heat had to be provided by an external fuel. This caused hot and cold areas to appear in the combustion and cooling zones of the furnace. The higher temperatures required to pelletize hematite and the heat transfer problem increased the clinkering tendency in the furnace, which disrupted uniform gas flow and produced a serious discharge problem.

Attention directed toward updraft furnace

Because of the operational limitations of the shaft furnace for agglomerating pellets of specular-hematite, the application of a traveling grate was

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the object of the pyrometallurgical research at Cleveland-Cliffs' Research Laboratory from July 1952, until the initial startup of the Eagle Mills pelletizing plant in September 1956.

There are two fundamental methods of firing green pellets on a traveling grate. The essential differences between the two methods are related to the direction of the gas flow and manner of bed feeding. Preliminary research on the downdraft method revealed that the drying phase of firing allows moisture to condense on the bottom layer of green pellets, and factors of gravity and pressure cause these pellets to mush into a congealed mass which is impervious to a gas stream. This condensation phenomenon places limitations on green pellet moisture content and workable bed depths. In the downdraft process, the bed depth is defined and critical, but in the updraft process the bed depth can be applied in incremental layers, at discretion, based on the progress of the firing cycle.

A number of advantages shown

The various departures involved with firing by the updraft method rather than the conventional downdraft method provide several distinct advantages, as follows: 1) There is no apparent limit of the maximum bed depth; 2) The combustion zone is the greatest source of dust, and when this is continually covered with wet pellets from stage feeding, the wet masses continually act as a dust filter; 3) Individual balling capacities are a fractional part of the traveling grate capacity, hence a specific balling device can form specific sizes of pellets, with particular quantities of fuel, and this charge can be placed in a specific location in the pellet bed; 4) It is possible to conduct all operations of firing, such as drying, preheating, ignition, combustion, recuperation, and cooling within the bed simultaneously; 5) The upward vector of draft imparts a semi-fluid state to the pellet mass which opens bed voids and prevents restrictions of gas flow; 6) The grate bars are never in contact with combustion products, hence are always the same temperature as the updraft stream of air; and 7) Bed pressures induced by pellet weight and compaction tend to be counteracted.

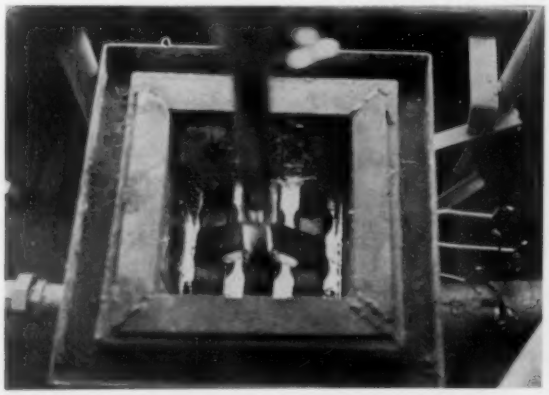
With the preliminary investigation revealing the updraft process as a favorable method of agglomerating specular-hematite concentrate, and because of the very limited amount of literature available concerning updraft firing, Cleveland-Cliffs directed a detailed research program toward agglomeration on the traveling grate by the updraft process.

Laboratory procedure and equipment

The laboratory apparatus consisted essentially of a downdraft line with auxiliary equipment for ignition, an 11 in. sq by 36 in. deep firing box, and an updraft line with blower to provide updraft air. A series of meters recorded the volume and vacuum of the downdraft air, the temperature of the hearth layer and the amount of propane used during the ignition period, the volume and pressure of the updraft air, and the temperature in the core of the pellet bed during firing at defined increments. All these data were recorded every minute during the test period.

The standard laboratory procedures used during this program included green ball formation, firing, and quality control tests on the green and fired products. Green pellets of a predetermined size were formed in a 12x16-in. diam laboratory batch balling drum. The product size was closely controlled by screening the drum product and retaining only the desired size pellets. These pellets were later added to the laboratory drum in 20-lb increments and re-rolled with the desired amount of powdered fuel. The fuel-coated pellets were separated into 5-lb portions and placed in pans near the furnace until they were required as feed to the grate.

Prior to firing green pellets by updraft, an ignition bed was prepared by placing sized, indurated pellets on the grates. This bed could be spread to any convenient depth, and it could be prepared with or without a layer of solid fuel on its surface. The burning ignition torch was spotted above the bed at a predetermined height, while a gentle downdraft was drawn through the bed. The downdraft air flow should remove the products of combustion from the ignition zone, but should carry away only a minimum amount of heat. These conditions were maintained for a fixed period of time which defined the ignition period. When this was complete, the torch was removed and green pellets containing fuel were placed on the incandescent bed. Updraft air was then forced through the system from the grate bottom, starting the firing period. Firing was maintained by continually placing a layer of wet



Laboratory pellet-hardening grate furnace. Ignition burner heating top of hearth layer to incandescence, after which green pellets were placed on the bed.

Commencement of updraft firing on laboratory grate furnace. Note shiny nature of top layer of green pellets from moisture condensation.

pellets with fuel on pellets that were in the process of being fired by updraft. When firing was complete, as evidenced by the maximum temperature of the products of combustion, the fired mass was cooled with a continual updraft stream. The cooled pellets were dumped into a receiver, weighed, and screened. The recovery, based on the amount of +3 mesh material, was computed from the screen analysis. A 20-lb representative sample of the recoverable product was subjected to a standard tumbling test, and the strength index of the grate firing test was determined from the screen analysis of the tumbled product.

Conclusions drawn from laboratory tests

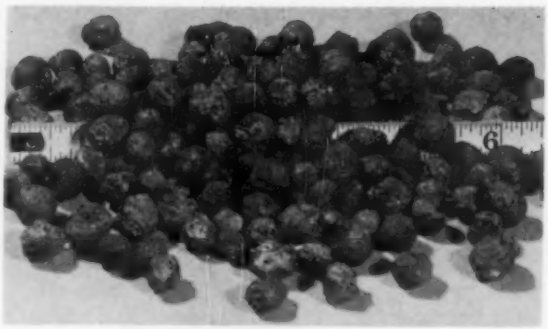
The results obtained from approximately 500 laboratory batch firing tests provided the following general conclusion for updraft firing. These results were used as a guide when designing the Eagle Mills pelletizing plant.

1) Specular-hematite flotation concentration consists of small micaceous flakes which range in size from 48 mesh to about 5 μ and are coated with a film of flotation reagent. This hydrophobic film of flotation reagent repels water from the mineral interface; the micaceous texture tends to cause the particles to plate on one another rather than key and interlock; and the absence of substantial quantities of -5 μ material does not allow the particles to compact readily. As these three factors are important to the formation of a stable green pellet, specular-hematite concentrate is one of the most difficult materials to ball.

2) Many additives were tried in an effort to correct this deficiency. Limestone and bentonite were found to improve not only the aggregating properties, but also the ultimate fired strength. To be considered as a favorable grate-machine feed, a $\frac{3}{8}$-in. diam pellet should have a wet compression strength of 2.0 lb and be able to withstand five 8-in. drops before rupture; it should have a dry compression strength of 8 lb and be able to withstand 20 3-in. drops before rupture. The omission of 2.5 pct limestone from the green pellet mix reduces the fired strength of the pellets appreciably. Ban and Erck[7] have shown the effect of limestone on the fired strength of pellets produced from specular-hematite concentrate.

3) Laboratory studies revealed that $-\frac{1}{2}$-in., $+\frac{3}{8}$-in. diam pellets at a moisture content of 9.0 to 9.5 pct produced the most favorable grate feed. Larger pellets do not dry as rapidly as smaller pellets and do not agglomerate as thoroughly, resulting in a poorly fired product and low capacities. Smaller pellets fire satisfactorily, but the possibility of the bed fluidizing is increased considerably. A fluidized bed always results in an unburned product. Green pellets containing 10 to 11 pct water usually possess a considerable amount of surface moisture which causes the pellets to coalesce under static or vibrating conditions. Congealed pellet masses are very impervious to a gas stream and cannot be fired adequately. Green pellets containing less than 9.0 pct moisture are usually weak and break in either the final stages of balling, conveying to the furnace, or impacts from furnace feeding.

4) The quality of green pellet fuels has a direct bearing on the quality of the fired product. Fuels for firing green pellets rank as follows: coke, anthracite, low volatile bituminous, and high volatile bituminous. The disposition of fuel on the surface of pellets is required because the hot firing zone



Specular-hematite pellets produced in laboratory updraft grate furnace proved to be of sufficiently high quality to warrant plant-scale operation.

ascends so rapidly (over 1 in. per min) that the fuel must be readily accessible to the updraft air. Internal fuel usually reacted as a reductant rather than as a fuel. The necessity of using surface fuel limited the size of the fuel to either a size similar to that of the pellets, or to a finely powdered form. Powdered fuel was chosen because of the greater possibility of being more uniformly distributed throughout the pellet bed. Fuel:pellet ratios on the order of 4.0 to 4.5 pct of the green pellet weight are adequate for proper firing. Fuel quantities in excess of this amount increase the strength indices, but also increase the clinkering tendencies which are detrimental to the firing operation. Smaller amounts of fuels cause a weak, partially fired product to be produced.

5) An updraft flow rate of 100 to 120 cfm per sq ft of grate area produces the most favorable product recovery and highest unit capacity. Excessive amounts of air will either cause the pellet bed to fluidize or strip the heat from the pellets before they are thoroughly fired. Both conditions will result in a poorly fired product. Lesser amounts of air usually result in the loss of ignition or decrease the unit capacity tremendously.

6) Bed depths of wet pellets 8 in. or less produce the most favorable firing conditions. If bed depths exceed 8 in., bed pressures become high, pellets near the surface of the bed become excessively wet and coalesce, the updraft flow of air may become preferential, and the pellet bed may fluidize. The only disadvantage of smaller bed depths is the increased number of feeding stages required for the same depth bed.

On the premise that the pellets are to be applied in 8 in. layers, the time increment between feeding stages is critical for a fixed combustion rate. If a short time increment exists between feeding stages, moisture precipitation can cause the upper layers of pellets to coalesce and interfere with uniform gas flow. If a long increment of time exists between feeding stages, ignition between consecutive stages can be lost or the capacity will be decreased considerably. An increment of 5.8 min between additions of 8 in. layers produced the most favorable product in recovery and capacity.

7) Ignition is established by placing a 4 in. layer of $-\frac{1}{2}$-in., +3 mesh indurated pellets on the grate, covering these pellets with a monolayer of the same size anthracite coal, and subjecting this layer to the flame of a gaseous fuel under gentle downdraft conditions. Closely sized pellets are required in the hearth layer to produce a porous bed and insure an

even distribution of heat. External gaseous fuel at 15,000 BTU per sq ft of grate area is required to successfully fire hematite pellets containing 9.0 to 9.5 pct water and 4.0 pct powdered fuel. The length of the ignition period is dependent solely upon the amount of BTU available to the hearth layer per unit of time. Laboratory data revealed that at the completion of the ignition cycle the surface pellets attained a temperature of 2200°F, pellets 2 in. lower reached 380°F, while pellets 4 in. lower were only 150°F.

Plant-scale operation

The results of the laboratory studies became reality in September, 1956, when the operation of the 2000 tpd pelletizing plant was started by the Marquette Iron Mining Co. at Eagle Mills, Mich.

Flotation concentrates produced at the Republic flotation plant are transported to the pelletizing plant by rail. As received, these concentrates contain about 6 pct moisture, and on an average they contain less than 50 pct −325 mesh material. Both the moisture content and the size consist are inadequate for good balling characteristics. To correct these deficiencies, the concentrates are metered out of the storage silos and transported by conveyor belt to the grinding section, which consists of two ball mills operating in open circuits. The ball mill pulp is pumped to disc filters which produce a filter cake containing 9.0 to 9.5 pct moisture.

The filter cake of proper size consistency and moisture is combined with predetermined quantities of bentonite and limestone to prepare the concentrate as balling-disc feed. This mixture of concentrate and additives is given a thorough fluffing and mixing in a PeKay mixer before being placed in the day bin, feeding the disc.

The thoroughly prepared fine material is metered out of the day bin at a controlled rate onto a conveyor belt. Although the concentrates have been thoroughly fluffed prior to the day bin storage, there is a tendency for these concentrates to re-compact, thereby affecting the balling characteristics. It is necessary, therefore, to recondition these fines before feeding the disc, and, a PeKay aerator was installed on the belt transporting the prepared concentrates from the day bin to the disc.

The fluffed and aerated fines are fed to the balling disc, where the fines are rolled in snowball fashion to the desired size green ball. Up to this point additions of coal have been purposely omitted from the process to avoid internal carbon content. As previously explained, it is quite necessary that the coal be added externally. To accomplish this, pulverized coal is added in metered quantities to the last stage of the disc operation. A fine spray of water is used at this point to assure adherence of the fine coal to the green ball.

Four discs are used to form the green balls coated with coal, and the product from each disc is fed to a different point on the traveling grate. The first disc product is fed directly on the hearth layer, immediately after the ignition section of the grate, at which point the updraft is started. The heat that has soaked into the indurated pellets during the ignition is then stripped from the hearth layer and ignites the coal in the first 8-in. layer of green balls.

This causes an induration zone to rise in the green pellet bed, and as this zone approaches the top of the first layer of green balls, the product from the second disc is placed on the bed. The induration zone continues passing through the first layer and starts igniting the second 8-in. layer of green balls. In similar manner the product from the third and fourth discs are fed to the grate machine until 32 in. of active green balls have been deposited.

Once induration has been completed, the volume of air is increased to complete the firing and at the same time extract the sensible heat from the top layer of fired pellets. These exhaust gases do not contain an appreciable amount of moisture and are used as the air source in the firing phase of the process.

The last section of the grate is used for downdraft cooling. Laboratory tests revealed that during the final phase of the updraft process there is a tendency for the top layers to remain hot. Adequate cooling of this layer of hot pellets is virtually impossible, but it has been found that by reversing the flow of air, the heat can be extracted from this layer and distributed through the mass, thereby reducing the hazard of discharging excessively hot material from the grate.

The machine discharge is screened for the purpose of eliminating fines from the shipping product. The fines are reground to obtain a size-consist similar to the original flotation concentrates.

Observations on initial plant operation

Troubles of every manner and variety have been encountered during the initial start-up of this plant, which was developed directly from laboratory scale tests. However, experience to date indicates that all the difficulties encountered are mechanical rather than process. We are confident of the success of this system in producing a pellet to meet all of the strict specifications, established in initial research studies for a satisfactory pellet for blast furnace or open hearth charge ore use.

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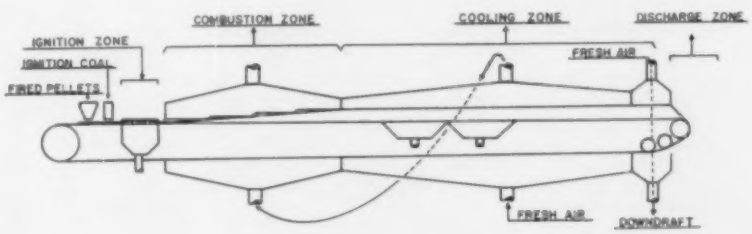
[2] T. E. Ban and L. J. Erck: *Laboratory Procedures for Determining the Pelletizing Characteristics of Iron Ore Concentrates*, *AIME Trans.*, August, 1953, vol. 196, pp. 803 to 811.



Simplified diagram of updraft, traveling-grate, pellet-hardening furnace at Eagle Mills, Mich. Plant is in full operation producing pellets for blast-furnace and open-hearth charging from — 325 mesh specular-hematite flotation concentrates produced at the Republic mine and mill.

by Alan English and M. F. Morgan

DOWNDRAFT TACONITE PELLET HARDENING

One line of research on iron taconite pellet hardening led to the adaptation of the downdraft continuous-grate furnace. Experimental and pilot-plant work proved so successful that a 3¾ million ton per year plant, based on this technique, was erected by Reserve Mining Co. at Silver Bay, Minn.

EXPERIMENTAL work on the concentration and agglomeration of low-grade iron ores was started many years ago at the Mines Experiment Station of the University of Minnesota by E. W. Davis and his staff. From these laboratory results and the work of O. G. Lellep, consultant for the Allis-Chalmers Manufacturing Co., there were indications that the use of a downdraft continuous-grate furnace, patterned from a conventional-type sintering machine, would be practical. Consequently, a pilot plant was designed and constructed by the joint efforts of Allis-Chalmers Manufacturing Co. and Arthur G. McKee & Co. at Carrollville, Wis. Several years of work resulted in plans to build a large-scale pilot plant for commercial application. Such a pilot plant, built at Babbitt, Minn., by the Reserve Mining Co., was designed to produce 1000 tpd.

Sufficient metallurgical and operating data were accumulated to permit the successful application to the design of a commercial plant of any desired capacity. Based upon this data, a pelletizing plant having a 3¾ million ton per year capacity was erected by the Reserve Mining Co. at Silver Bay, Minn. and started operation in October, 1955. Provisions were made in the design to permit future expansion to a capacity of 10 million tons per year.

Raw materials for furnace

Raw materials used in both the experimental and the commercial plants were similar and consisted of magnetic taconite concentrates, anthracite fines, bentonite, and fuel oil. The magnetic concentrates, crushed to −150 mesh, contained 75 to 85 pct −325 mesh, and an analysis showed 64.5 pct total Fe, 9.0 pct SiO_2, 0.53 pct CaO, 0.67 pct MgO, 0.55 pct Al_2O_3, and 0.22 pct Mn.

Anthracite coal fines were used in all test work, but there is no reason why coke breeze or other forms of carbon could not be used. The most desirable size of solid fuel for pelletizing has always been a subject for discussion, and the downdraft pelletizing process has been no exception. However, coal ground to −28 mesh has been used successfully in commercial plants. In the experimental stages −100 mesh and −200 mesh sizes were used, but the benefits from better distribution, expected of the finer sizes, were never realized. At the present time, no commercial plants are using coal ground finer than 28 mesh, and any additional benefits which may be derived from the use of finely ground coal must be carefully evaluated, due to the additional cost of grinding. The analysis of the anthracite coal, on a dry basis, was approximately 81.0 pct fixed carbon, 7.0 pct volatile matter, and 12.0 pct ash, with a rated heat value of approximately 13,000 BTU per lb.

Bentonite has been used as an additive almost since the inception of the pelletizing process. There are a number of different types of bentonite, each having different characteristics, but the Wyoming type, which has been most commonly used, was employed in the majority of the test work on the downdraft continuous-grate furnace. An approximate chemical analysis of this type of bentonite averages 22.0 pct Al_2O_3, 64.0 pct SiO_2, and small amounts of other materials, such as lime, soda, and ferric oxide.

The liquid fuel must supply the thermal needs required by the process. In all pilot work, No. 2 fuel oil was used, but No. 6 fuel is used in commercial plants, and both have an approximate heat value of 150 BTU per gal.

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Balling drums

Balling drums were used initially in downdraft pelletizing for the production of green balls and have continued to be used as the process was developed, simply because they always have given satisfactory results. The objective of the balling drum is to produce green balls of the desired size, having sufficient strength to withstand handling with a minimum amount of degradation.

Recent balling tests, using magnetic concentrates containing 8.9 pct H_2O, showed an average wet strength of 1.17 lb and a dry strength of 0.72 lb when no additive was used, but when 0.5 pct bentonite was added, the wet strength increased to 1.30 lb, and the dry strength increased to 4.79 lb.

Experimental and commercial furnaces

The main principle of pelletizing with the downdraft continuous-grate furnace, which embodies some of the features of a sintering machine, is the recovery and use of most of the sensible heat for drying and burning the product.

The experimental furnace, 17 ft long 2 ft wide, was divided into four windboxes, or zones, designated as updraft drying, waste gas, recuperation, and cooling; it was equipped with an ignition furnace containing three compartments for downdraft drying, preheating, and final ignition.

The effective windbox area on the furnace was divided into zones to use approximately 11.8 pct for updraft drying, 70.6 pct for downdraft drying, preheating, ignition, burning, and recuperation, and 17.6 pct for downdraft cooling. The purpose of first using updraft air for partial drying was to prevent moisture from condensing on the balls in the bottom layers of the bed. Balls containing an excessive amount of water tend to collapse under the weight of the balls above and result in numerous operating problems, such as an impermeable bed, low burning rates, and the production of an excessive amount of fines. The temperature of the air used for updraft drying was about 400°F and was recovered from the cooling zone of the grate furnace. For starting up purposes and to raise the low temperature of the air from the cooling zone, an air heater was used as needed. The air used for downdraft drying, preheating, and ignition was recovered at about 700° to 800°F from the recuperation zone. The final temperatures of about 800°, 1000°, and 2350°F, respectively, was accomplished by burning propane gas.

In the case of the commercial downdraft continuous-grate furnace, the coal-coated balls, produced in the balling section of the plant, are fed onto the grate by a vibrating-screen feeder. This feeding arrangement is of vital importance to the process to maintain a clean, level bed and to obtain good airflow and good permeability during the various phases of the operation. Bed height has also been given considerable attention, as maximum bed thickness will obviously give lower ignition fuel rates and promote maximum recuperation of hot air within the bed. However, bed height is a function of grate speed for a given production. In actual operation a bed height between 10 and 12 in. appears to give the best results. The balls are subjected to the same treatment on the grates in the commercial operation as outlined for the experimental downdraft grate furnace, except that greater attention was given to updraft drying and cooling. The grates are 6 ft wide and 168 ft long and have 28 windboxes divided into five sections or zones, designated as the updraft drying, waste gas, recuperation, first-stage cooling, and second-stage cooling. The windbox allocation for these zones is as follows: numbers 1 to 7, updraft drying; 8 to 11, downdraft and preheat drying (waste gas); 12 and 13, ignition (waste gas); 14 to 22, burning and recuperation; 23 and 25 first-stage cooling; and 26 to 28, second-stage cooling. Windboxes 8 to 28 are on downdraft.

Updraft drying is accomplished by utilizing 900°F air from the recuperation zone and the first-stage cooling zone of the furnace. This drying is accomplished in 25 pct of the total length of the grate.

Downdraft drying, preheating, and ignition utilize recuperated 900°F air in a large ignition furnace which is divided into three sections. The recovered air is raised to the required temperatures by burning No. 6 fuel oil. Temperatures of about 1400°F for drying, about 2000°F for preheating, and 2350°F for final ignition are used. These steps of the process are accomplished in approximately 21.5 pct of the total grate length. The remaining 53.5 pct of the grate is used for burning and cooling purposes.

Burning and cooling of the balls is accomplished by pulling large volumes of air through the bed of pellets. The actual temperatures in the recuperating windboxes are about 1250°F, but, because of the type of fans used in the process, tempering must be carried out to reduce this temperature to 900°F.

Temperatures of approximately 900°F are also obtained from the first-stage cooling section, and this is all used for updraft drying purposes in the first three windboxes, the remainder of the updraft drying air being obtained from the recuperation section. Air temperatures of approximately 700°F

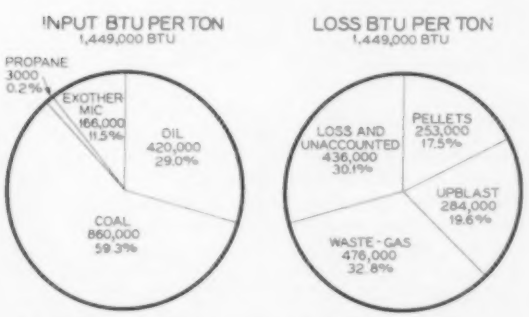

Fig. 1—Heat Balance on commercial, downdraft, continuous-grate furnace; input at left and consumption at right.

Table I. Typical Heat Balance for Downdraft Continuous-Grate Furnace Producing 2400 tpd

	BTU per Ton Pellets	Pct Total Input or Consumption
BTU Input		
Fuel oil	420,000	29.0
Propane gas	3,000	0.2
Anthracite coal	860,000	59.3
Exothermic reactions	166,000	11.5
Total	1,449,000	100.0
BTU Consumption		
Pellets	253,000	17.5
Updraft hood exhaust	284,000	19.6
Waste gas fan exhaust	476,000	32.8
Loss and unaccounted	436,000	30.1
Total	1,449,000	100.0

are obtained from the second-stage cooling section, but this air is not used at the present time.

Pellets that have been subjected to this particular treatment and discharged at temperatures of approximately 600° to 700°F are water cooled and screened before being stockpiled or loaded into lake carriers.

A practical heat balance for the production of 2400 tpd on a downdraft traveling-grate furnace is shown in Table I.

Operating results

The last of the six downdraft continuous-grate furnaces at Silver Bay, Minn., was placed in operation more than one year ago. Since that time, excellent progress in production rates has been made. The plant was designed for a total production of 12,000 long tons of pellets per day, but it is now averaging between 15,000 and 16,000 tons per day.

The pellets produced analyze about 63.0 pct Fe and 9.7 pct SiO_2. The quality of the product is determined by the standard ASTM tumbler test and is considered good, averaging about 12 pct of the −28 mesh fraction. This tumbler test consists of revolving a 50-lb sample in a tumbler drum at the rate of 25 rpm and screening at 28 mesh.

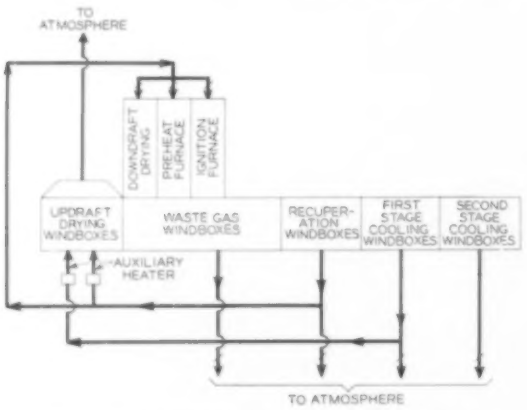

Fig. 2—Air flow diagram for the commercial, downdraft, continuous-grate furnace. Grates are 6 ft wide and have 28 windboxes divided into five sections: updraft drying, waste gas, recuperation, first-stage cooling, and second-stage cooling.

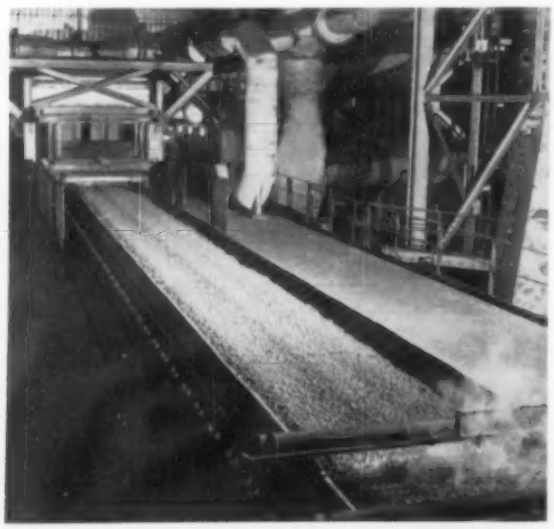

Fig. 3—Pelletizing furnace bakes pellets at 2400°F. Pellets lie on grate about 1-ft deep and are cooled gradually before being quenched in water.

Engineering features of the commercial plant

In designing the plant, it was specified that a few hours supply of concentrate for pelletizing should be available in the event that the concentrator should be shut down for some reason, and if the pelletizing plant was down, then sufficient bin capacity should be available to keep the concentrator operating for a few hours. This was accomplished by installing large storage bins, each bin serving a closed balling drum circuit by means of a table feeder. There are three balling drum circuits, including coal coating drums, operating with each grate furnace to produce a ball approximately of $\frac{3}{8}$-in. size.

Control equipment proportions the bentonite into the concentrate, and the coal onto the surface of the green balls. The same type of control equipment is used for regulating the feed to the furnace.

As stated earlier, feeding the grate-furnace is accomplished by means of a vibrating screen. The fines of balled concentrates are screened out, and the feed is evenly distributed across the 6-ft width of the grate. Feeding the grate was quite a problem during the development stages and was solved only by the ingenuity of the operators in collaboration with the screen manufacturers.

The design of the grate furnaces and the ductwork to take care of the heat problems, that were apparent when handling large volumes of hot air at different temperatures, was quite an engineering feat. The ductwork was designed to take care of expansion in all directions. The fans were designed to handle 900°F air.

The product handling arrangement is such that the product from the machine passes over a grizzly screen set at 4 in. The oversize is crushed to 4 in. by means of a single roll crusher. The −4-in. product is wet screened over a single deck, two section, vibrating screen at 3/16 in. and 1½ in. The −3/16-in. fines are wet classified at 28 mesh with the −28 mesh size returning to a fines recovery system and the +28 mesh size passing as product. Clinkers of pellets larger than 1½ in. are water quenched in a drum before joining the remainder of the product to be conveyed to the stockpile or to product handling facilities for loading into lake carriers.

The fines recovery system consists of a central pumping station, which handles the return fines from all grate furnaces, a hydroseparator, a thickener, and a filter.

General comments

There are a number of phases of this operation that are considered most important for a successful downdraft continuous-grate furnace operation and must be emphasized. At all times good balls must be produced; the balls must be distributed evenly across the grate furnace at the desired bed height; correct proportioning of bentonite to the concentrate and coal to the formed balls is essential; and regulation of temperatures and airflows to maintain continuity of operation is of primary importance.

by F. D. DeVaney

PELLETIZING IN SHAFT FURNACES

Another line of development for the agglomeration of ores and concentrates is the shaft furnace. For very fine ores, this process offers advantages in fuel economy and low capital installation cost, while continuing to produce a high quality blast furnace material.

IT is of great interest that the various organizations engaged in the search for a cheap and efficient agglomeration process for fine magnetite concentrates—essential if the taconites are to be utilized—have ended up with processes that are basically different. This paper describes the development and the present status of the shaft-type furnace as now utilized by the Erie Mining Co., which is managed by Pickands Mather & Co.

The shaft furnace has always had an appeal to metallurgists because of the simplicity of the design and the possible low fuel consumption. Work done on pelletizing at the University of Minnesota Mines Experiment Station by E. W. Davis and his associates determined that it was possible to roll up fine magnetite concentrates in a balling drum, and that, if such balls were fired at a sufficiently high temperature, a hard, indurated pellet, well adapted for use in a blast furnace, could be made. Early furnaces had no heat recuperation and the heat consumption was in the order of 2 million BTU's per long ton.

Early attempts with pebble stove furnaces

Erie initially attempted to secure high heat recuperation by the use of two, parallel, pebble-stove-type furnaces in which the stoves were blown alternately. This design had excellent heat economy but proved unworkable in practice. The next development was the placing of one pebble stove directly above the other with a relatively narrow neck between. Cold air was blown up the bottom of the lower stove and most of this preheated air was bypassed into a combustion chamber where the temperature was raised to approximately 1800°F. This hot gas was then brought into the upper stove, where the actual induration of the pellets occurred.

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Under laboratory conditions, this furnace, which was of 30-in. diam, performed well and gave an excellent product with a heat consumption in the order of 300,000 BTU per ton. A commercial size 12-ft diam furnace was then built along the same general lines, with a rated production of 600 tpd. This capacity was never achieved and numerous difficulties developed in feeding the pellets, in the flow of material through the restricted area between the two stoves, and in discharging fused chunks. It was also very apparent that problems of material flow and gas distribution were much more serious in a large diameter shaft than in a small one.

The rectangular furnace

The next development was the construction of a rectangular furnace in the place of the round furnace. This incorporated other changes in design that led to the development of a successful process, mainly the installation of an improved feeder, the removal of all constrictions in the shaft, and the installation of chunk breakers for breaking up the occasional cluster or chunk that might be formed.

In the development of the rectangular furnace, the Lebanon Div. of Bethlehem Steel Co. worked closely with Erie. Ideas were freely exchanged and furnaces were built both at Aurora, Minn., and at Lebanon, Penn., for pelletizing fine magnetite.

Preparation of balls

The preparation of balls suitable for feed to the shaft of a furnace presented many problems. The balls formed must have sufficient cohesiveness and strength so that they can be handled over the necessary conveyors and furnace feeders and deposited intact on the feed line of the furnace. In order to produce good balls, it is necessary to control the moisture of the feed to the balling drum and maintain a proper condition of the rolling surface. Such a drum was ultimately developed by the invention of a reciprocating cutter bar, which controls the

thickness of the cake on the inside surface of the balling drum but yet gives a surface which is relatively rough and not glazed or smooth; thus, the balls being formed will roll rather than slide. It is essential that the balls be formed slowly so that they have a high density; it is also essential that the balls be rather closely sized and that no fines be permitted to enter the furnace. In the balling drum, as developed by Erie, this is secured by placing a trommel at the end of the drum with openings that are approximately $\frac{5}{8}$ in. All balls that are finer than this size are conveyed back to the feed end of the drum where they join the new feed to the drum. Bentonite, added in amounts of 10 to 15 lb per long ton, markedly increases the strength of the balls in the dry state, and to a somewhat lesser extent, in the fired state.

Furnace operation

The furnace now in use at the Erie plant consists of a rectangular shaft 6 ft wide x 14 ft long and approximately 45 ft high. The shaft is full at all times with pellets and an amount is drawn off from the bottom at the same rate the green balls are fed into the top, so as to keep the feed line uniform. The amount of pellets in the furnace is about 180 long tons, and these move continuously down the shaft at a rate of ½ to 1 in. per min, depending on the feed rate. The pellets from the balling drum are charged onto the feed line of the furnace by a special feeder which travels in a rectangular path.

The furnace operates on a counter-flow principle. As pellets descend, they are heated in the upper shaft by gases from the combustion chamber and by preheated air coming up the shaft. The indurated pellets below the ports are cooled by an uprising current of air blown into the furnace at the level of the chunk breakers; this tends to abstract the heat from the descending pellets. Approximately 35 pct of the total air is admitted to the two combustion chambers, one on each side of the furnace. In these combustion chambers, the incoming air is heated to a temperature of approximately 2350°F. This hot air enters the shaft proper through a series of ports and rises up the upper portion of the furnace, where the pellets reach temperatures above 2400°F. Pellet temperatures in excess of the combustion chamber temperatures are reached because the mineral being indurated is magnetite, and since the atmosphere in the furnace is strongly oxidizing, the magnetite is almost entirely converted over to hematite with the liberation of approximately 207 BTU per lb of iron in the pellets. This furnace operation is unique in that, with the exception of the upper few inches at the top of the furnace, the pellets are always at a higher temperature than the ascending gases. The surfaces of the pellets are cooler than their interiors, which creates partial fusion conditions in the interior but not at the surface. This is important, as it lessens any tendency of the pellets to stick together and insures satisfactory material flow.

The hot gases rising up through the shaft encounter the charge of green unfired balls which are being deposited continuously, and these green balls abstract the heat from these gases, giving a top gas temperature which is normally in the order of 300°F. The heat line in the furnace can be nicely balanced by adjusting the rate of blow to the amount of feed.

The heat gradient in the upper part of the furnace is very sharp; the incoming green balls are at atmospheric temperature, and within a distance of 10 in. they reach a temperature near 2400°F. The balls remain at this temperature in the furnace until they have reached the level of the ports carrying in the air from the combustion chambers. Below these ports the pellets are progressively cooled by the upcoming air admitted at the chunk breaker level and are discharged at the bottom relatively cool. The temperature of discharge varies with the rate at which the furnace is being operated, and, to a certain extent, on the amount of cooling air being blown.

Chunk breakers

Chunk breakers are installed at two levels in the furnace. These consist of water-cooled shafts on which are mounted tooth-like projections which break up any descending clusters. The upper set has three shafts in which the rows of teeth are spaced 14 in. apart. Their main purpose is to break up any large chunks that may inadvertently be formed. The lower set of chunk breakers consists of four similar shafts, but on which rows of teeth are placed 5 in. apart, at which size the fired material can readily be discharged through the restricted furnace discharge legs.

The discharge openings are free to the air and a calculated loss of air through these openings is taken, which amounts to between 3 and 5 pct of the total air blown. The loss of air is held to this amount by restricting the diameter of the discharge pipes. By such a design it is possible to eliminate the need for mechanical devices for minimizing the loss of air. The cooling air is admitted to the furnace through the louvre-like devices, having long, slot-like openings. This air effectively cools the chunk breakers, and, of course, the descending pellets.

One of the main functions of the chunk breakers, in addition to breaking the occasional chunk that is formed, is to regulate the flow of material down the shaft. We have found that, with normal operation, the amount of material that requires breaking in the furnace will not exceed 5 pct, but the chunk breakers give a more uniform descent of material. As a direct result of this, a more uniform flow of air up through the shaft is achieved, and thus the over-all performance is materially improved.

Divider plates assist heating

Near the feed line of the furnace there are a number of divider plates on each side of the furnace. These divider plates are spaced about 18 in. apart; there are eight of them on each side of the furnace. They are made of a chrome-nickel casting, and their purpose is to divide the down-coming, and as yet, still unfired pellets, into zones. The passage of air is always greatest near a wall, and such dividing plates furnish additional wall area. Their presence assists in securing more uniform heating of the green balls and the prevention of masses of consolidated material which have lost most of their pellet structure.

Heat is supplied to the combustion chambers by the burning of oil. This oil may be either a light fuel oil or a heavy residual oil such as Bunker C.

If high-grade magnetite concentrates are used, or if the furnace is operated at a moderate rate, no other fuel is required. If the furnace is operated at maximum capacity, 10 lb per long ton of coal is mixed with the concentrate. At high capacity rates, this small amount of fuel tends to insure kindling of the magnetite in the pellets, giving a more uniform heat distribution over the upper part of the furnace charge.

The amount of air required is very close to the theoretical amount necessary for heat interchange, taking into consideration the weight of the pellets and their specific heat, and the weight of the air blown and its specific heat.

Refractory problems are minimal

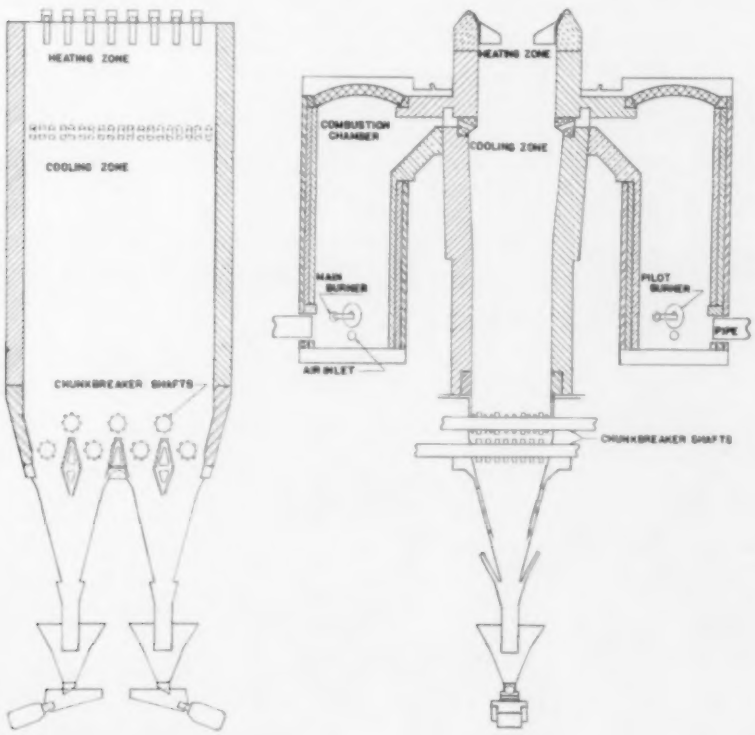
Brick work in this type of a furnace presents no great problem, since the temperatures never reach an excessively high point. The main portion of the shaft is lined with a good quality fire brick, and the lower portion of the main shaft is lined with a hard brick to withstand the abrasion of the pellets which become harder as they are cooled. Insulating brick was used at one time in the shaft proper next to the shell, but this construction has been abandoned due to the tendency for gases to abrade holes in this softer brick. In the combustion chamber, where there is no differential in pressure, insulating brick is used between the shell and the fire brick interlining. Life of the fire-brick lining is not known, but it is evident that several years of life can be expected before a relining job is necessary.

Green pellet feeding important

Correct feeding of the pellets onto the stockline of the furnace is of great importance. Balls must be deposited evenly over the surface of the bed to secure a definite pattern, and this cycle must be so regulated that green balls are deposited on the charge at about the time that the heat line has advanced to one or two-ball depths below the top of the furnace. This is accomplished by having the feeder traverse a rectangular path and spread the balls out by means of a flipper at the end of the conveyor. The feeder is so designed that exactly the same number of balls will be laid down in a definite time interval, whether the feed belt is advancing or retracting. The feeder is also designed so that if a low place occurs in the bed, the feeder, by means of a traveling feeler, slows down its rate of travel across this area and deposits a heavier load of balls. The feeder is also provided with a mechanism which measures the height of the charging line, and this in turn regulates the rate of discharge from the bottom of the furnace so that the feed line is always at a uniform level. The furnace is entirely automatic and requires little attention.

Losses kept to 10 pct

In the Erie pelletizing operation the furnace discharge is screened, and all material finer than −3/16 in. is reprocessed. The product shipped is usually sprinkled with water to allay any dust that may arise; 1 pct water in the pellets is sufficient to prevent the formation of dust. Undersized material is screened, and all material coarser than 14 mesh is reground. This reground material, together with the relatively small amounts of dust that are collected from the top dust collector and a dust collector handling the furnace discharge, are reprocessed. In practice, the total amount of dust formed is about 4 pct, and the amount of chips needing reprocessing is about 6 pct, making a total of approximately 10 pct that must be reworked. One of the



Shaft furnace for pellet hardening at Erie Mining Co.'s plant in northern Minnesota. The furnace consists of a rectangular shaft 6 ft wide x 14 ft long and approximately 45 ft high. Chunk breakers are installed at two levels in the furnace to break the occasional chunk that is formed and to regulate the flow of material down the shaft. The plant—managed by Pickands Mather & Co. and designed for 24 shaft furnaces—is nearing completion with 12 already in operation.

inherent advantages of the shaft pelletizing process is the production of a sized product containing no fines, with the necessity of reprocessing a relatively small amount of undersized material.

Operating statistics

Data given in Table I represents the production from a single furnace for the month of September 1956.

The low BTU consumption compared with other forms of induration is secured by the high degree of heat recuperation. As the table indicates, the average top gas temperature is only 238°F, and the bottom discharge temperature, even at this high production rate, is 508°F. These temperatures, compared to the temperature at the indurating zone, 2450°F, indicate the degree of recuperation. There is a decrease in the iron content of the pellets as compared to that of the feed; this comes about largely because of the oxidation of magnetite to hematite, and it is also shown by the furnace recovery of 102.21 pct. The furnace yield figure shows that during this particular month almost 12 pct of the furnace feed reported as chips or as dust and was reprocessed. During this entire month, there were no delays for major repairs nor for metallurgical reasons. The total delay time was due to scheduled repairs and minor mechanical delays.

Erie Mining Co.'s large new plant at Aurora, Minn., is nearing completion and the pelletizing plant consists of 24 shaft furnaces. As of Jan. 1, 1958, twelve of these furnaces had been completed and were in successful operation. Together, the 24 furnaces will have a combined capacity of at least 7½ million tons of pellets per year or about 21,000 tpd. These furnaces will be operated in units of four with a crew of three men to look after the balling and pelletizing operation for each four-furnace unit.

Operating costs

Some comments are probably in order relative to operating costs. The fuel consumption of this process as compared with other methods of agglomeration is unquestionably lower. As far as additives are concerned, these are in the same order as those required in grate machines in which balls are pelletized. The total power consumption in a shaft furnace procedure, including all auxiliary operations, such as balling, induration, dust collection, and regrinding of chips, is in the order of 20 kw-hr per ton of pellets produced. This is of about the same order required in the grate sintering of balls, but it is somewhat higher than that required for sintering and nodulizing. At first thought, it might seem that the cost of operating labor for shaft furnaces might be higher than for other processes because of the capacity of each individual furnace. However, because of the relative simplicity of operation and the ability of operators to look after a number of furnaces, this operating labor charge is about the same as for other processes. Maintenance and repair labor on the shaft furnaces as now developed is believed to be lower than other agglomeration processes because of the relatively few moving parts in the shaft furnace. Such furnaces have only a mechanical feeder, slow-moving chunk breakers, and a relatively simple vibrating discharging device. There are no other moving parts.

Capital costs

The initial cost of any agglomeration plant is not low. A figure in rather general use in the trade is that the cost of a modern sintering plant is in the order of $6.50 per ton of annual capacity. While the cost of constructing a shaft-type pelletizing plant will vary for different locations and for different types of material, it can be definitely stated that the comparable cost for a shaft pelletizing operation will be less than for sintering. Features of this process and its apparatus are covered by patents and patent applications, and arrangements have now been made to engineer and construct such pelletizing plants for industry.

In conclusion, it may be stated that the shaft furnace has definitely found a place in industry for the induration of fine magnetite concentrates, and it also appears to have interesting possibilities for other materials. Twenty-one of these furnaces are now in use in this and other countries, and there are under construction 14 additional furnaces which will be in operation in 1958. A number of other installations in various parts of the world are also presently being given serious consideration. The acceptance of this furnace has come about largely because of the quality of the product, the low fuel consumption possible, and economies in both the initial capital and operating costs.

Table I. Operating Statistics for Experimental Shaft Furnace, September 1956*

Pellets		Additives, lb per ton	Pellets	Feed
Pellet production, tons	30,637	Coal	15.7	14.0
Fe in feed, pct	64.09	Bentonite	15.4	13.7
Fe in pellets, pct	63.12	Soda ash	1.6	1.5
Quality, tumble test No.	85.3	Fuel oil, gal per ton	4.3	3.8
BTU consumption, per ton of pellets in cars	753,680			
Operating Data				
Pellets, tons per operating hr	47.14	Air to pellet ratio	1:1	
Total air pressure, psi	6.0	Air to combustion chamber, pct	37	
Air volume, std cfm	22,300	Total availability, pct	90.27	
Furnace recovery, pct	102.21	Avg product, tons per sq ft per day	12.16	
Furnace yield, pct	88.04	Max product per calendar day, tons	1212	
Temperatures, °F				
Avg top gas exit temp	238			
Bottom discharge temp	508			
Combustion chamber temp	2350			

* **Definitions**

Tonnages: Dry, long tons

$$\text{Total availability} = \frac{\text{Hr actually operated}}{\text{Total hr in period}}$$

$$\text{Furnace recovery} = \frac{\text{Total tons discharged from furnace}}{\text{Total dry tons material charged to furnace}}$$

$$\text{Furnace yield} = \frac{\text{Total tons pellets shipped}}{\text{Total dry tons material charged to furnace}}$$

$$\text{Avg production per sq ft per day} = \frac{\text{Tons pellets in cars}}{\text{No. of days operated} \times \text{cross sect. area of furnace (84 sq ft)}}$$

by Kurt J. E. Meyer and Hans Rausch

THE LURGI PELLETIZING PROCESS:
A COMBINED UPDRAFT-DOWNDRAFT TECHNIQUE

Problems imposed by the development of the present-day beneficiation processes for low-grade iron ores in America, as well as in Sweden and in Germany, have stimulated development of pellet-hardening techniques in all three countries. Lurgi is the leading German firm to have played an important role in this development.

MAGNETIC concentrates of very small particle size must be converted into agglomerates that can be transported with ease and used economically in blast furnaces and open hearth furnaces. These concentrates do not vary in their physical or chemical properties except over long periods of time. This has made it possible to establish quite definite methods for their treatment without having to make allowances for variations in the quality of the raw material. All American and Swedish pelletizing plants are equipped accordingly.

A pelletizing plant in Germany, however, must be able to process ores of different origins, having quite different characteristics. This requirement was of great importance for the development of the Lurgi process. For the production of green pellets a machine would, therefore, have to be capable of dealing with all kinds of raw materials, and hardening must be done in a furnace, the temperature of which is adjustable to the different temperatures of the ores.

Making green pellets

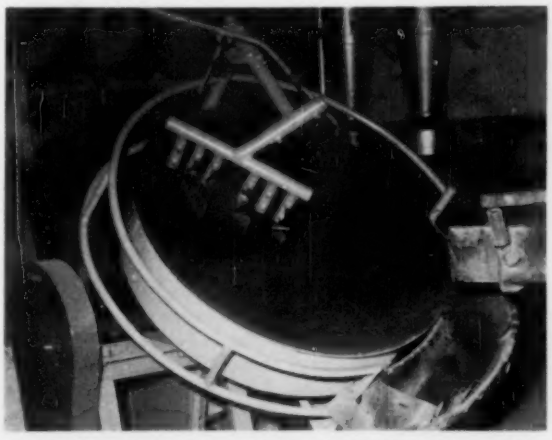
To produce green pellets, experiments were made on a number of machines, such as drums, vacuum extrusion presses, and compacting machines. In 1949, Lurgi was the first to use pelletizing discs to produce iron ore pellets; until then this type of machine had been used exclusively in the cement industry. The first experimental disc had a 2½-ft diam, but substantial modifications became necessary before the disc met all requirements presented by the various ores.

Balling machines working under pressure cannot be used without limitations, and the extrusion press is suitable only for sufficiently plastic ores or for mixtures with plasticizing additions. In other respects, too, the extrusion press shows remarkable differences compared with the pelletizing disc and the drum, especially with regard to the strength, bivalent iron content, and the uniformity of the pellets. These differences become evident by comparison of the same material produced in the extrusion press and in the pelletizing disc, shown in Table I. The test material used was Swedish concentrate with an addition of 20 pct red mud, i.e. tailings from the Bayer alumina process.

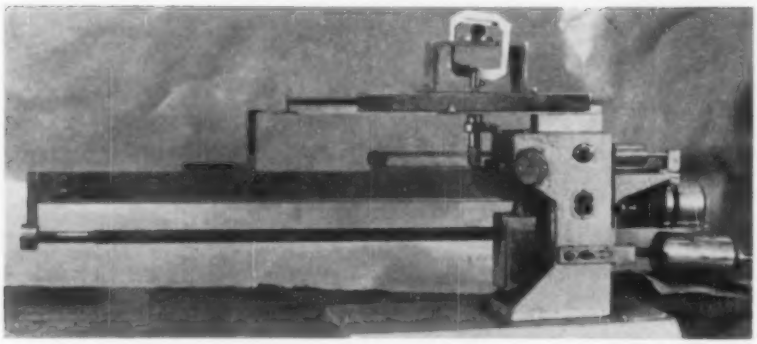
Although having a number of advantages, particularly concerning high capacity, the pelletizing drum has one decisive drawback; it does not discharge green pellets of even approximately the same diameter, therefore, each drum has to be followed by a screen to separate the undersize. This rough treatment, as well as several subsequent conveying operations, requires a minimum strength that green pellets made from only a few ores possess without additives. Therefore, it becomes necessary to add binders to increase the green strength of the pellets. So far, bentonite is the most widely used.

In comparison with the drum, the pelletizing disc offers some noteworthy advantages, such as its light weight, a greater possibility of varying the depth, the angle of inclination, and the speed of rotation. Moreover, the disc discharges green pellets of almost equal diameters which makes screening unnecessary.

KURT J. E. MEYER and HANS RAUSCH are with the Lurgi Gesellschaft für Chemie und Huttensesen mbH, Frankfurt am Main, Germany. This paper was presented at the 1957 AIME Annual Meeting.



Pelletizing discs, such as this one of 3 ft diam, offer great versatility and discharge green pellets of almost equal diameters.



Testing green compression strength of pellets is done on this apparatus. A weight is guided by the lower worm-gear, which is moved along the lever arm by a motor. The crushing of the ball breaks a contact, and the weight stops, thus indicating the load.

Table I. Comparison of Hardened Pellets from the Extrusion Press and the Pelletizing Disc[1]

	Extrusion Press	Pelletizing Disc
Total Fe content, pct	62.4	62.1
Thereof bivalent Fe, pct	8.3	3.65
Crushing strength, lb per ball	432	640
Diam of pellets, in.	⅝ to 1¾	¾ to 1

[1] Pellets of Swedish iron concentrate with addition of 20 pct red mud, i.e. tailings from alumina production by Bayer process.

Table II. Determination of the Compression and the Drop Strengths of Green Pellets

	Magnetite	Limonite Concentrate	Flotation Calcine
Green compression strength, lb per ball	2.4	8.2	2.2
Drop Tests:			
Triple fall, height, in.	10	3	8
strength, lb per ball	1.7	8.6	1.5
Single fall, height, in.	24	108	20
strength, lb per ball	1.6	8.4	1.7
Moisture content, pct	12.5	16	13
Diam of pellets, in.	⅝ to ¾	⅝ to ¾	⅝ to ¾

Table III. Comparison of Green and Dry Strength Values for Different Iron Ores and Concentrates

	Flotation Pyrite Calcine	Magnetite B	Magnetite B + 0.75 Pct Bentonite	Limonite Concentrate
Green strength, lb per ball	3.5	5.9	6.2	8.2
Dry strength, lb per ball	3.1	5.5	30.9	29.6
Moisture content, pct	27	9.5	9.7	16.0
Diam of pellets, in.	¾	¾ to 1	¾ to 1	⅝ to ¾

Table IV. Strength of Hardened Pellets as a Function of the Rate of Heating

Ore	Diam, In.	Heating Program	Strength of Hardened Pellets, Lb per Ball
Magnetite	¾ to 1	Drying at 392°F, slow increase to the hardening temp, 2314°F	805
Magnetite	¾ to 1	Drying at 752°F, preheating 1472°F, hardening at 2314°F	584
Magnetite	¾ to 1	Drying at 752°F, then immediate hardening at 2314°F	540

Table V. Dependence of Pellet Strength on Final Hardening Temperature

	2134°F	2224°F	2404°F
Magnetite concentrate strength, lb per ball		220	637
Hematite concentrate strength, lb per ball		348	767
Calcine strength, lb per ball	672	949	

The latter fact and the use of a special conveying system for the handling of the green pellets make the addition of binding agents unnecessary. This is a special feature of the Lurgi process, namely, that in the majority of cases green pellets are produced without the addition of binding agents; however, the green pellets do have to have a certain minimum strength to withstand the transportation from the balling machine to the burning apparatus.

Test methods for green pellets

To determine the behavior of green pellets, the following test methods were applied: determination of green compression strength and drop tests, comprising a) three drops and b) one drop. Testing of the green compression strength was done on a special apparatus in which the forces applied range up to 100 lb in four stages. A weight is guided by the lower worm-gear, which is moved along the level arm by a motor. The crushing of the ball breaks a contact, and the weight stops, thus indicating the load. In each test 10 balls are pressed from which the average is taken. The determination of the green strength is important for transportation as well as the behavior of the green pellets in storage and on the sintering bed.

Drop tests consist of dropping simultaneously 10 green pellets from defined heights. All green pellets must withstand the triple and single fall without damage, i.e. the strength test, which is repeated after the drop test, must not show considerably lower values than those determined previously. Table II gives a survey of the test results obtained with balls of different ores.

Drying green pellets

Knowledge of the properties of dry pellets is of great importance. Many pellets have less strength in a dry state than when wet, while pellets of very few materials show a considerable increase in strength when dry. This is illustrated in Table III.

Pellets of ores that have a sufficiently high green and dried strength, or that show an increase in crushing strength after drying, may be dried in an installation separated from the sintering machine, for instance in a combined drying and feeding bin. This will increase the output of the sintering machine.

Hardening and cooling pellets

Preliminary tests for hardening were carried out in an electric muffle furnace with about 20 to 50 pellets. On the strength of the results of these tests, further ones were then performed with 110 to 220 lb of pellets on a sintering pan. The pan is designed so that the bed depth may be increased or decreased by adding or removing side wall elements. The windbox

under the grate may be connected to the suction or pressure pipes. The heating of the pellets is accomplished by means of a burner hood on top of the sintering pan. The burners may be used with fuel oil or gas.

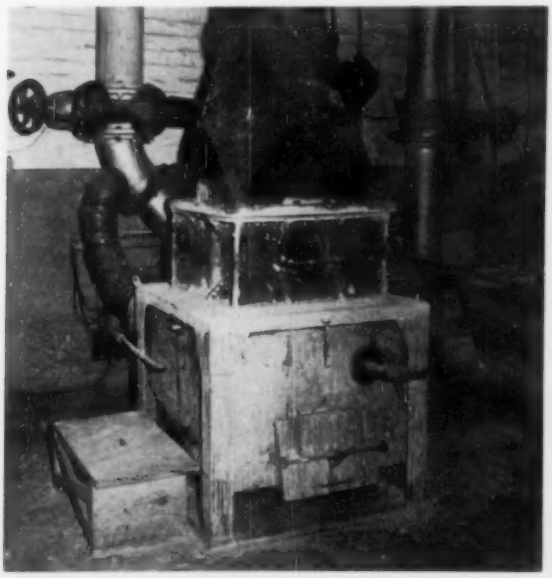
Of prime interest in hardening and cooling is the dependence of the quality of the finished pellets on rate of heating, temperature, time of hardening, type of cooling, and gas atmospheres.

As has also been discovered by other experimenters, the quality of the pellets, especially that of magnetite pellets, is sometimes affected by the rate of heating. If heating is too rapid, the hardened pellets frequently have a scaly structure which easily breaks into fragments and generally has little strength. The sound pellets were partly crushed by force to demonstrate their uniform structure. Hematite is generally not so sensitive to rapid heating, because there is no oxidation to Fe_3O_4 involved. The strength of pellets as a function of the rate of heating is illustrated in Table IV.

Apart from the rate of heating, it is frequently necessary to maintain the final temperature for some minutes, in the interest of the sound quality of the pellets. The effect achieved thereby is considerable, the strength sometimes being increased up to 50 pct. The final temperature is also an important factor, as is shown in Table V.

Cooling is likewise of importance. Pellets of known properties were slowly cooled and then suddenly quenched in water. The results showed clearly that the loss in strength is much greater the larger the temperature differential. Rapid or slow cooling in air also caused considerable differences, as was shown in experimental work.

Finally, the influence of the gas atmosphere on the degree of oxidation, and thus on the quality of the pellets, was considered. Maintaining an oxidizing gaseous atmosphere during the final hardening is demonstrated by Table VI. The production of highly oxidized pellets is particularly difficult when the ores contain carbon, e.g. in the form of blast-furnace flue dust.



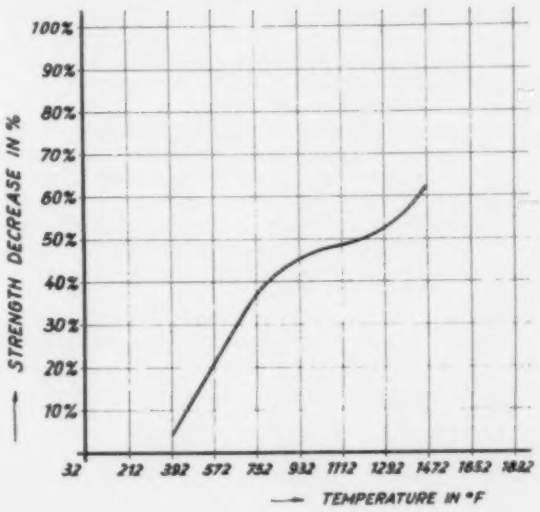
Pan for drying, hardening, and cooling pellets. Heating is accomplished by the burner hood, while the windbox may be connected to suction or pressure pumps.

Testing pellet quality

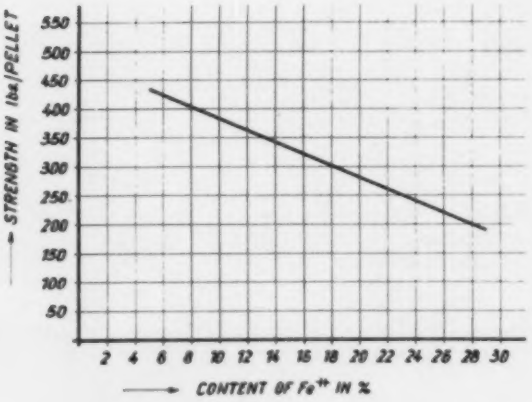
To judge the quality of the hardened pellets, the following characteristics were tested: crushing strength, degree of oxidation, porosity, abrasion, drop tests, and freezing tests.

The crushing strength is determined in a hydraulic press between two steel plates. The apparatus has two measuring ranges: one from 0 to 1300 lb and another from 0 to 5300 lb. The strength is indicated in lb per ball, and at least 10 balls are crushed and the average taken. The degree of oxidation is computed in the known way after analyzing the total iron and the bivalent iron content according to Tigerschiöld.

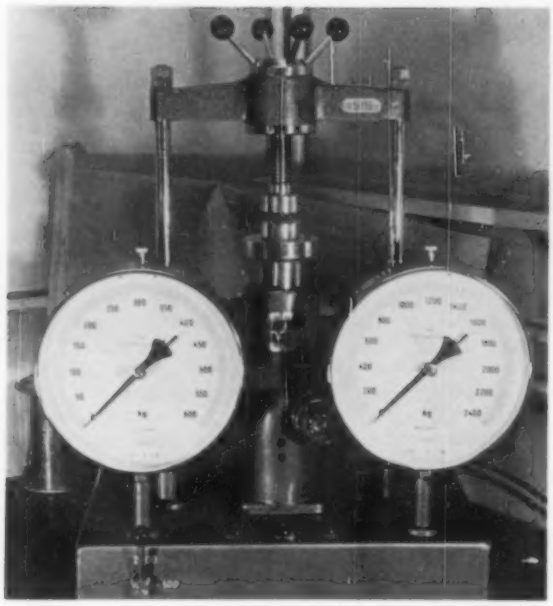
The porosity is computed using the formula, $(D - d)100$, where D is the true specific gravity and d is the apparent specific gravity. The true specific gravity is determined in a pycnometer with benzene which penetrates into the pores, while the apparent specific gravity is measured by means of a special pycnometer with mercury.

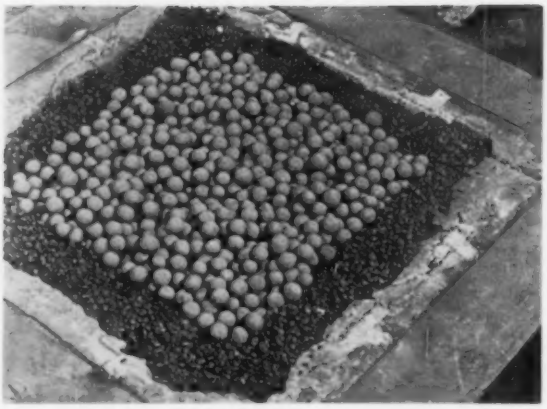


Quenching temperature and pellet strength. Higher quenching temperatures mean greater decrease in strength.



Pellet strength and bivalent iron content, which is controlled by oxidizing degree of gas during final hardening.





Above, a bed of pellets with a side-wall layer of —⅝ in. of hardened balls and fragments on experimental pan. On the machine such a layer protects side walls and pallets against excessive heat strains.

Left, crushing strength of hardened pellets is determined in a hydraulic press between two steel plates. At least ten balls are crushed and the average taken.

Abrasion is determined by tumbling in drums with and without a churning blade. The performance of drop tests is simple.

As many ore deposits are located in polar regions, the behavior of pellets at low temperatures and when repeatedly frozen and thawed again is interesting. For this purpose finished pellets are wetted, rapidly cooled down to −94°F in carbon dioxide snow and then instantaneously thawed again with hot water. This test may be repeated several times. Table VII shows the result of such a freezing test carried out with pellets of different magnetite concentrates. The results show that these pellets are insensitive to atmospheric influences.

Experiments on pilot-plant scale

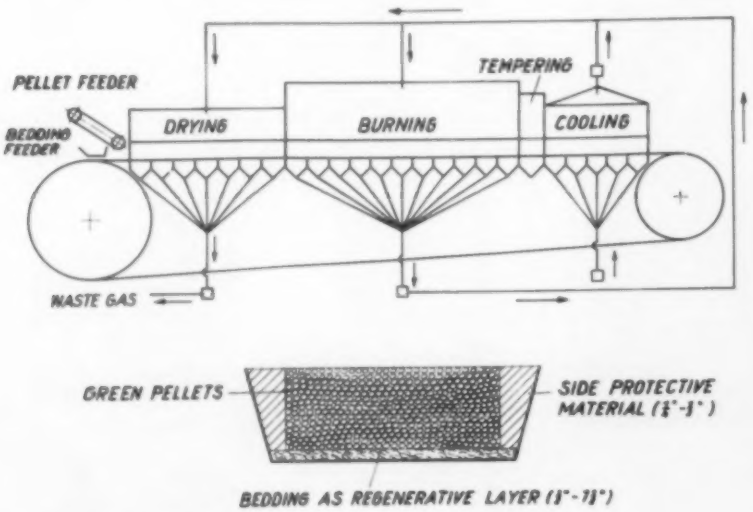
The best of the laboratory-scale tests were continued on a pilot-plant continuous sintering strand. For this purpose a pelletizing plant, consisting of material storage bins with adjustable discharge, pelletizing disc, and sintering machine of 16 sq ft windbox area, with all necessary fans, was installed in the works area of the Reichswerke at Watenstadt, Germany. The pelletizing plant was also equipped with the necessary conveying installations and with sufficient measuring instruments. In this plant, which can be operated either with updraft or downdraft cooling, drying can be carried out either on the sintering strand or in the feeding bin. Hot waste gases can be recirculated. The pellets are heated by oil or blast-furnace gas.

The results of the pilot-plant tests corresponded to the laboratory pan tests, as is shown in Table VIII.

Application to industrial-sized plants

All laboratory-scale tests were carried out on a gas-fired sintering pan in a batch operation. The fundamental knowledge learned from this method was then successfully applied to the pilot plant stage, and the experience gained from both proved the process to be worthy of use in industry. Further investigations toward this final aim included studies of transportation and the most economical flow of gases in the system.

Pelletizing discs: For large capacities, a pelletizing disc with 16-ft diam is used. It is able to produce



Schematic layout of a Lurgi pelletizing machine with pallet feed. Special features of the process are that (1) addition of binders is not necessary and (2) gas or oil are used exclusively as fuels not incorporated in the pellets. The latter permits greater control of temperature and oxidizing conditions on sintering machine. Magnetite, hematite, limonite, or mixtures of these may be pelletized by this process.

about 18 to 20 tons per hr of green pellets of 1 to 1¼ in. diam. If balls of smaller diameter are produced, the capacity is higher. The speed of rotation is about 4½ rpm, with an angle of inclination of about 48°. No auxiliary equipment is needed, except suitably attached scrapers to prevent the building up of deposits on the floor and the side walls. Water, as far as necessary, is sprayed on through nozzles arranged over the disc. No binders are added. Arrangements have been made for a gentle handling of the balls, which are wet and sensitive to drops. As the disc produces balls of almost uniform diameter, eliminating the undersized material by screening is not necessary.

A special green-pellet handling system is used at the charging point of the machine in order to separate broken balls or fragments thereof from the feed. It consists of an inclined conveyor belt running upwards, the inclination and the speed of which can be varied. The speed of the balls rolling down this inclined belt is slowed by rubber baffles, and all irregularly-shaped pieces, as well as fines, are carried up and discharged over the head pully. Furthermore, this system increases the mechanical strength of the balls considerably by its rolling action. It is also an excellent method of feeding the balls onto the machine evenly distributed across the width of the pallets.

Pellet-hardening furnace: In a pelletizing plant, the sintering machine itself is subjected to quite different conditions than in the ordinary sintering operation and must be equipped accordingly. A particular requirement is to protect the side walls and pellets against excessive heat. In charging, therefore, a grate layer of hardened balls and fragments, —⅝ in., is fed onto the grates. This also serves as a regenerator to preheat the cooling air up to a certain degree when moving into the updraft zone. The side walls are covered with finer particles recirculated from the discharge of the machine and charged on to the pellets from a storage bin.

Besides offering an excellent protection against heat for the metallic side-wall plates of the machine, the side-wall layer also has another advantage; the pellets along the sides of the bed are heated more uniformly and, therefore, correspond in quality with those in the center of the bed. By careful screening of the side-wall layer it is also possible to avoid the marginal effect on the gas flow which would otherwise conduct most of the hot gases down along the side wall plates, due to the smaller resistance toward the flow in this region.

The drying of the pellets is done under suction, with heated cooling air coming from the end of the machine and circulated gas from the windboxes serving as drying media. After drying, the pellets are steadily heated until they reach the necessary hardening temperature. This temperature is held for several minutes, so that there is sufficient time for crystalline transformations to take place. This too, is done under downdraft with the gases recirculated and leaving the system through the drying zone as waste gases.

In the cooling zone, cold air is blown into the wind boxes and passes through the bed, cooling pellets, hearth layer, and hot pellets, thereby becoming heated itself. The hot air is drawn from the surface of the cooling zone and fed into the gas circulation system. At the discharge end a screening station separates the material into finished product, grate layer, and side-wall layer.

Special features of the process

The process developed by Lurgi, using gas or oil heating only, differs in the following characteristics from other processes:

a) The addition of binders for improving the quality of the green pellets and the addition of materials for increasing the ultimate strength is not necessary.

b) By using gas or oil exclusively as fuels not incorporated in the pellets, it is possible to regulate the burning process on the sintering machine accurately and to produce and maintain the temperature required in each case.

c) The use of the sintering machine as a burning apparatus permits the regulation of the vacuum in individual windboxes and thereby the control of the gas flow through the charge in each separate stage and consequently also a very close control of the reaction.

d) By closing the valves on one or two windboxes after the pellets have been heated to the final temperature, the flow of gas through these can be stopped completely, which improves the strength.

e) The pellets are cooled by updraft through the last windboxes, which is advantageous, not only from a mechanical, but also from a process point of view. Thus, the air first cools the grates and the grate layer and reaches the hot pellets in the first stage of cooling in a preheated state, which is of importance for the final strength of the balls.

f) The exclusive use of gas or oil for heating makes it possible to produce suitable and different gas atmospheres, whether oxidizing, neutral, or reducing, at definite points of the machine.

g) The process makes it possible to pelletize magnetite, hematite, limonite, or mixtures of these.

The first pelletizing plant using the Lurgi process was built for the International Nickel Co. of Canada at Coppercliff, Ontario, Canada, for production of about 1200 tpd. In the US, the Dravo Corp. of Pittsburgh has been licensed to construct this equipment.

Table VI. Strength of Hardened Magnetite Pellets as a Function of the Degree of Oxidation

Bivalent Fe Content, Pct	Strength, Lb per Ball
1.7	949
5.8	622
8.3	606
16.1	291

Table VII. Performance of Hardened Magnetite Pellets During Freezing Tests

Ore	Strength in Lb per Ball		
	Hardened	Cooled to —94°F, 5 Cycles	Thawed Again
Magnetite A	1323	1257	1147
Magnetite B	992	970	970

Table VIII. Comparison Between Pilot-Plant and Laboratory Pellet Tests

	Hematite Concentrate		Magnetite Concentrate	
	Plant	Laboratory	Plant	Laboratory
Hardened pellet strength, lb per ball	353 to 419	375 to 441	882 to 1102	882 to 1102
Porosity, pct	8 to 9	—	24	27
Total Fe, pct	51.4	51.1	68.5	68.8
Bivalent Fe, pct	2.8	1.5	1.3	1.5

by L. F. Theys and L. V. Lee

SULFATE ROASTING COPPER-COBALT SULFIDE CONCENTRATES

This is the story of the successful application of fluidized bed technique to a series of reactions taking place within narrow ranges of operating conditions, and the steps by which Union Miniere passed from laboratory to full-scale operation.

KATANGA Province of the Belgian Congo is the site of Union Miniere's large copper and cobalt production facilities. Here, surface oxide ores composed primarily of malachite, $Cu(CO_3)Cu(OH)_2$, are mined. A flotation concentrate of this ore is leached with sulfuric acid, and copper and cobalt are successively extracted electrolytically from the leach liquor. Although these surface oxide ores are still extensive, deeper penetration will bring up sulfide and mixed sulfide and oxide ores. The copper in these sulfide ores is present as chalcocite, Cu_2S, usually accompanied by cobalt as carrollite, Co_2CuS_4. With a deadline of 1959 for a new full-scale operation, the Research Dept. of Union Miniere started work in 1952 at their Jadotville laboratories to develop a good method of treatment for these subsurface sulfide deposits.

Early in 1956 this search was culminated by the successful start-up of a commercial-scale fluosolids system in Jadotville, sulfate roasting 80 metric tons per day of rich copper-cobalt sulfide concentrates. These elements are thus solubilized so that subsequent treatment is essentially the same as that given the original oxide concentrate leach liquors. At the same time, the new sulfur is utilized as acid for leaching.

A partial sulfating roast

Strictly speaking, a sulfating roast should result in the combination of the sulfate radical, $SO_4^=$, with every possible metallic group present. Actually, the reaction desired for copper-cobalt concentrates could more accurately be termed a partial sulfating roast, since the temperature is adjusted above the decomposition temperature of the undesirable iron sulfates and below the decomposition temperature of the desirable sulfates.[1]

There is some uncertainty concerning the mechanism by which the change from metallic sulfide to metallic sulfate takes place. Some believe the oxide must first be formed and then combined with sulfur trioxide gas to produce the sulfate. Others favor the view that the sulfide is oxidized directly to the sulfate, and that it is more difficult to sulfate a metal with no sulfur in its molecule than one that is tied to a sulfur atom. Whatever the mechanism, the fact that sulfating can be used to solubilize copper and cobalt, now that controlled roasting is feasible and that even selective sulfation is possible, if needed, places a powerful tool in the hands of metallurgists.

The promise held by sulfate roasting led to a consideration of the roasters available. An ideal unit should 1) impose a certain oxidizing potential on each particle being roasted, and 2) maintain a certain temperature on each particle in the reaction zone. Both of these variables ideally should be known and controllable at will by the operator.

Sulfate roasting at Jadotville

A consideration of the foregoing and tests with hearth-and-rabble type roasting by Union Miniere Research Dept. led to a program of exploring fluidized bed roasting. Below are the reactions it was hoped could be effected on concentrates averaging about 50 pct Cu, 2 pct Co, 12 pct S, and 2 pct Fe, with the copper largely as chalcocite, the cobalt as carrollite, and the iron as pyrite:

$$Cu_2S + 5/2\,O_2 \rightarrow CuSO_4 + CuO$$
$$Co_2CuS_4 + 7O_2 \rightarrow 2CoSO_4 + CuSO_4 + SO_2$$
$$FeS_2 + 11/4\,O_2 \rightarrow 1/2\,Fe_2O_3 + 2SO_2.$$

Equipment; A 4-in. diam unit, modelled after those used by Dorr-Oliver Inc. in their Westport, Conn. laboratories, was first built. Tests on this unit were followed by the construction of a 27-in. unit. Both of these units were electrically heated and dry fed. The data from the second unit confirmed that from the first, and the results may be summarized under the headings of the principal operating variables.

Roasting temperature: These temperatures were varied from 550° to 700°C. The extraction of copper from the resulting calcines by a weak sulfuric acid leach was over 90 pct at 550°C and rose to between 97 and 98 pct at 675°C. For cobalt, recoveries of from 90 to 95 pct could only be obtained by roasting at 675°C. The solubility of the iron under leaching

L. F. THEYS is Director, Research Dept., Union Miniere du Haut Katanga, Jadotville, Belgian Congo, and L. V. LEE is Technical Representative, Dorr-Oliver Inc., Johannesburg, Union of South Africa. Paper presented at the AIME Annual Meeting, New Orleans, 1957.

conditions diminished as the roasting temperature increased, a favorable tendency. Between 675° and 700°C, approximately half of the small amount of iron present in the feed remained in the leach residue. At these temperatures, approximately 20 pct of the relatively small amount of sulfur present in these concentrates was lost up the stack as SO_2 instead of forming SO_3 and combining with solids to form sulfates. This loss increased directly with temperature. At temperatures in excess of 700°C, complexes of copper, cobalt and iron, which were insoluble under the moderate leaching conditions used, apparently started forming.

Air:feed ratios: Too large an air:feed ratio wastes heat and wastes cross-sectional area in the roaster. With the excellent gas-solids contact possible in this type roaster, only 20 to 30 pct air in excess of the quantity actually used for the reactions shown above was needed.

Detention time: Up to a certain point, increases in detention time, like increases in temperature, serve to increase the extraction of copper and cobalt when leached, and to increase the insolubility of the iron with the same leaching. It is this tendency that makes the product carried out of the roaster to the dust collectors poorly sulfated compared to the product overflowing from the fluidized bed of solids. This makes it desirable to keep carryover as low as possible by keeping gas velocities low.

Typical results from the 4-in. unit with dry feed blown in from the bottom appear in Table I.

With simple sulfuric acid leaching, the extractions in this test were 97.9 pct Cu, 96.2 pct Co, and 67.4 pct Fe. The leach residue represented 18.2 pct of the weight of the roasted product and contained 4.51 pct Cu, 0.79 pct Co, 2.52 pct Fe, and 1.42 pct S. The increase in the dry weight of the feed, due to roasting, was 21.8 pct.

Once it had been shown that good metallurgical results were obtainable by roasting Katanga sulfide concentrates in this manner, emphasis changed from the chemical studies, such as the sulfating reactions, the loss of SO_2 up the stack, and the acid balance in the leaching circuit, to the engineering required for transposing the roasting done so far to a commercial scale. There was experience to draw on from fluosolids plants roasting pyrites, zinc, and copper-zinc concentrates elsewhere in the world, but the commercial roasting of this unusually rich Katanga copper-cobalt concentrate, of course, brought its own crop of problems.

The commercial-scale roaster

The design of the commercial-scale sulfate roasting plant at Jadotville was aimed at having a unit to 1) roast 80 metric tons of concentrates per day, on a dry basis, 2) fit into the larger plant required by 1959, and 3) have sufficient flexibility to roast a variety of concentrates under a variety of conditions. With Dorr-Oliver S.A. of Brussels, a fluosolids plant was designed and built which satisfied these aims It has now been operated long enough to establish the approximate optimum roasting conditions and to study the materials handling problems involved in bringing up feed and taking away calcine.

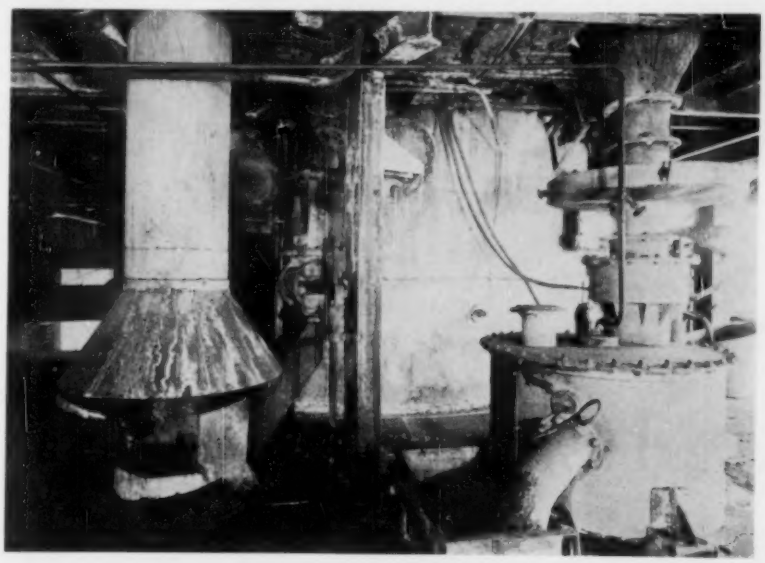
Feed Section: Repulping equipment was installed to receive concentrate from the Kolwezi concentrator, repulp it to a slurry of 76 pct solids, screen out any trash, and pump the concentrate to a suitable storage tank. From this storage tank, slurry was metered into the roaster by a variable speed Mono pump. It was demonstrated here, as it has been elsewhere, that heavy-duty equipment is required to repulp flotation concentrate filter cake that has been stored. A helical-rotor-type pump, the Mono, was found entirely suitable for pumping slurry to the roaster at an even, controllable rate.

Roaster: The roaster had an inside diam of 14 ft and was equipped with oil burners for heating during start-up, a refractory-brick lining, and a constriction plate for even distribution of roasting air across the horizontal cross section of the roaster.

Fluidizing air system: Air was introduced below the constriction plate through suitable piping and measuring and flow regulating devices from a Roots-type blower.

Instruments: Sufficient instrumentation for nearly automatic operation was provided, including six-point temperature recorder, bed temperature recorder-controller, four-point pressure indicator, and air flow recorder.

Calcine collection system: For collection of the dust in the outlet gases from the roaster, a single, unlined, mild steel cyclone with stainless steel



Fluidized bed roasting unit for sulfate roasting copper-cobalt sulfide concentrates at Jadotville, Belgian Congo. Center background is 14-ft roasting unit. Overflow calcine from roaster is withdrawn dry and quenched in launderer at left. At right, dust collected from the outlet gases in a cyclone falls directly into quench tank. Unit is capable of roasting 80 metric tons of Kolwezi concentrates per day.

vortex finder, was provided, followed by a Peabody scrubber receiving spent liquor from the tank house. The dust from the cyclone fell directly into a quench tank, and the overflow calcine from the reactor was withdrawn dry and then quenched in a launderer.

More complete descriptions of fluosolids systems similar to this one can be obtained from the References.[2,3,4,5]

Commercial scale operation

The large-scale fluosolids system at Jadotville was run for a period of several months. During this time the principal equipment changes made were as follows:

1) Capacity of the slurry preparation system had to be enlarged so that it was capable of repulping more solid material and of removing more trash than had been expected.

2) The injection of the slurry feed into the roaster had to be adjusted to ensure that this rich concentrate was well distributed.

3) Agglomeration occurred in the roaster which required higher space rates than those dictated by the screen analysis of the feed. This agglomeration reduced the dust carryover to a range of 20 to 25 pct in contrast to the 50 to 60 pct generally obtained in other installations.

4) A bottom draw-off was added to the roaster because of the possibility that severe agglomeration might result in segregation of particles. Actually, in most instances the largest particles came off with the bed overflow indicating that the agglomerated particles were porous.

When changes had been made to allow for the foregoing findings, the plant was operated steadily for three months. Typical operating data and corresponding leaching results appear in Table II. A typical set of size analyses for the feed and the corresponding overflow and cyclone product appear in Table III.

Table I. Typical Laboratory Data

Feed Analysis				
Cu, Pct	Co, Pct	Fe, Pct	S, Pct	Bed Height, In.
46.63	4.03	1.08	15.80	35.4

Excess air (sulfating basis), pct	35
Roasting temperature, °C	706

Product Analyses					
	Pct by Wt	Cu, Pct	S, Pct Total	S, Pct Sulfate	S, Pct Difference
Overflow from bed	97.2	38.53	10.82	10.77	0.05
Cyclone	2.8	26.43	10.85	10.25	0.60
Dust in bag filter	negligible	—	—	—	—
Total	100.0	38.19	10.82	10.76	0.06

Table II. Typical Commercial-Scale Results

Feed Analysis			
Cu, Pct	Co, Pct	S, Pct	Bed Height, Ft
59.00	1.92	15.1	5

Excess air (sulfating basis), pct	25
Roasting temp, °C	675

Product Analysis*					
	Approx Pct by Wt	Cu, Pct	Co, Pct	S, Pct Total	S, Pct Sulfate
Overflow from bed	71	42.9	1.53	9.39	9.29
Cyclone	26	40.1	1.40	8.4	7.5
Scrubber	3	28.9	1.00	13.5	13.3

* Sulfuric acid leaching dissolved 94 pct Cu and 89 pct Co in the combined overflow and cyclone products.

Table III. Commercial-Scale Size Analyses

Feed	Overflow		Cyclone Product	
	Mesh, Tyler	Pct by Wt	Microns	Pct by Wt
93 pct −325 mesh	+10	11.2	+74	5.2
	−10 +20	16.1	−74 +37	39.0
	−20 +35	29.1	−37 +19	28.6
	−35	43.6	−19 +11	17.2
			−11 +4	10.0

Conclusions

1) The results obtained in the 14-ft roaster closely paralleled those in the 4-in. and 27-in. test units.

2) The original faith placed by Union Miniere in sulfate roasting by means of the fluid bed technique was justified. The process is entirely workable. Research now will be aimed at obtaining even higher copper and cobalt recoveries and at perfecting the slurry preparation system, rather than at any basic aspects of the process.

3) An ample range of throughputs and concentrate analyses can be comfortably handled; the richest tested contained 61 pct Cu and 16.5 pct S; the weakest, for thermally autogenous roasting in a 14-ft unit, contained 46 pct Cu and 12.0 pct S. The iron in both these concentrates was less than 2 pct.

4) A steady feed rate is important to the maintenance of the desired sulfating conditions in the roaster. Feeding concentrates as a slurry appears to provide good assurance of getting this steady feed rate on a commercial scale.

5) An important result to Union Miniere is the final distribution of the sulfur content in the Katanga sulfide concentrates. All testwork to date has shown that about 80 pct of the sulfur in the feed reports in the roasted products. Of this amount a small percentage is lost during leaching, the remaining is regenerated into H_2SO_4 when $CuSO_4$ is electrolyzed to cathode copper in the tank house. This H_2SO_4 is utilized for the leaching of malachite concentrates.

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In a later issue, Journal of Metals expects to present an article by L. Theys giving the latest operating results of the fluidized-bed, sulfate roasting plant at Jodotville, Belgian Congo.

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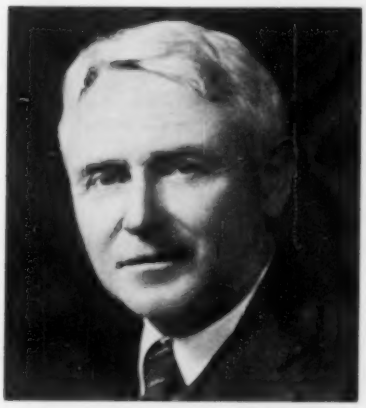
AIME NEWS

AIME Elects Three To Honorary Membership

Three members of the Institute were elected to Honorary Membership by the Board of Directors at the November 18 meeting. To be installed at the AIME Annual Banquet on February 19 are Donald H. McLaughlin, C. E. Mathewson, and Fred Searls, Jr. The citations in their honor are to be announced later.



D. H. McLAUGHLIN

Donald Hamilton McLaughlin, mining geologist and engineer, was born in San Francisco in 1891. He attended the University of California, graduated with a B.S. degree, and obtained his A.M. and Ph.D. degrees from Harvard University. Well known as a consulting geologist and mining engineer, he has served numerous mining companies—as a member of the board as well as consultant—including Cerro de Pasco Copper Corp., Homestake Mining Co., International Nickel Co. of Canada Ltd., Bunker Hill and Sullivan Mining and Concentrating Co., and The Dorr Co.

Mr. McLaughlin's early professional experience was gained as chief geologist for Cerro de Pasco in Oroya, Peru, where he participated in the establishment of the geological department.

Mr. McLaughlin has been active in the affairs of the Homestake mining Co. for over 30 years, taking part in a variety of things from geologic studies to the current debate about the value of the product of the mine and the recent expansion into uranium mining and milling. He was chosen president of the company in 1944.

Besides his lengthy association with commercial concerns, Mr. McLaughlin has had considerable experience in the technical education field. Of particular pride to him are his years as chairman of the Div. of Geological Science at Harvard, his association there with Graton, Daly, Palache, and other colleagues, and with many students who later made successful careers for themselves in mining geology.

Among his numerous *extra-curricular* activities has been his work for AIME—Vice President, Director, and President in 1950. Mr. McLaughlin is a member of various technical and professional organizations: SEG, Mining and Metallurgical Soc. of America, and the Geological Soc. of America. His government advisory activities include a stint as chairman of the AEC Advisory Committee on Raw Materials during its first five years. His educational interests have extended to his present mem-

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C. E. MATHEWSON

Education Symposium Held In Detroit

Nicholas M. Lazar was the official AIME representative to the Accreditation Symposium sponsored by ASME in Detroit on Nov. 7 and 8, 1957. Mr. Lazar represented President Holt and the Institute at the Symposium, purpose of which was to disseminate more widely information relating to the accrediting methods of ECPD and particularly to stimulate awareness of the responsibilities of technical society members in this concern.

Upon his return from the meeting, Mr. Lazar reported on the Symposium and his reactions as a delegate. His summary follows.

> "The purpose of this seminar was to acquaint people in industry with the problems of engineering accreditation and to get them interested in serving on accreditation committees. J. H. Davis, President of Stevens Institute of Technology gave the introductory remarks. He discussed the problems in mechanical engineering education. Necessarily the basic engineering education is a compromise between quantitative and qualitative factors and standards. There is also a question of how long the program should last—four, five, or six years. How practical the education is to be—should it be for design, development, research, or some other aspect?
>
> "In view of the rapid technological progress, should education change more rapidly? In the present engineering curricula, as a result of outside pressures, a great deal of time is given to non-technical subjects. Should this trend continue, and if so, where will the technical subjects be taught?
>
> "The general philosophy of the accrediting program is to

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Augustus B. Kinzel
AIME President 1958

DR. Augustus B. Kinzel, AIME President 1958, joined the Institute in 1926, significantly, the same year that he began his association with Union Carbide Corp. He has been actively engaged in research and allied areas with this corporation ever since, and is today vice president-research. Born in New York City in 1900, he graduated from Columbia in 1919, from MIT in 1921, and from the University of Nancy, France, in 1922. He holds the degree of D.Sc from the University of Nancy, honorary degree of D.Eng. from NYU, and an honorary doctor of science degree from Clarkson College.

One of the nation's leading research metallurgists, Dr. Kinzel pioneered in ferroalloys, deoxidation, alloying of steels, welding and cutting, and in pressure vessel design. In the 1930's he fathered many of the then new low-alloy structural steels. More recently he spearheaded the research and piloting of Union Carbide's new process for making titanium metal.

Having contributed both practically and theoretically in a variety of fields, Dr. Kinzel relishes a position in his organization which might be illustrated by the backhanded introduction a shop foreman had at one of Union Carbide's customers plants: "Joe, I want you to meet Kinzel, he's a doctor but he knows what he is talking about."

There are turning points in almost everyone's career, and characteristically Dr. Kinzel looked at fundamentals in a first key career decision. Dean Kepple of Columbia had counseled that the easiest route to a successful career was through a successful company, and that the most successful were sound growth companies. Augustus B. Kinzel chose Union Carbide Corp.

Dr. Kinzel could not pick his battlefield nor choose his weapons at the second turning point in his career—but thoroughness and respect for fundamentals made the most of the situation presented. At this time the first large all-welded pressure vessel was tested at three times working pressure. It blew up, although supposedly designed for five times working pressure. Riveted vessels had heretofore been tested at only 1½ times working pressure because rivets began to leak at pressures above this.

After exhaustive study on the all-welded unit, top men concluded that the welds were okay, and that the steel was okay—failure notwithstanding. Soon after he joined Union Carbide it fell to Dr. Kinzel to review this analysis. He also concluded that the materials and construction were as specified and that the steel had failed at ultimate strength. When a check of the handbook-based design proved this correct, he went back to fundamentals and derived the design formulas. The designs in the boiler code dated back to the 1890's and were approximations. Careful calculation revealed that stress concentration at the head corners was about 2/3 higher than it was supposed to have been. Dr. Kinzel went on to design an elliptical head that eliminated the corner stress, a design in the code today.

One other incident illustrates his approach to problems. Over the years he found that he gave a great deal of advice and consultation on the use of materials in aircraft design and it occurred to him that he had a limited firsthand knowledge of flying. "It was a little like a man advising on solutions to New York City's traffic problem who did not hold a driver's license." He learned to fly well enough to get a private pilots license, as a result he feels that he gained a much greater perspective on the problems of aircraft design. Continuing to fly he terms himself a fair weather pilot, "I'm acutely aware of the difference between the amateur and professional, particularly when it comes to flying."

Despite diversified professional and technical activity, Dr. Kinzel still finds time for hobbies in which might be included his continuing love of flying, of sailing, and particularly of designing and building contemporary furniture. Undoubtedly some of these activities were neglected the year that he married off four daughters (a son is a senior at Yale).

Traveling a great deal for his company and his profession from his base of operations in New York, Dr. Kinzel also has homes in the Berkshires and in La Jolla, Calif. There are two guideposts to possible identification: If you see a man in a plane who is not deep in a book—be it technical, historical, biographical, or fiction—it is not Dr. Kinzel. If you see a man at a meeting, a session, behind a desk, but without a pipe, it is not Dr. Kinzel.

With a wide range of activities in metallurgy, applied mechanics, industrial gases, and nucleonics, he is co-author of volumes on alloys of iron and of chromium, author of more than 60 technical papers, and more than 40 patents bear his name. Dr. Kinzel has given many of the honorary memorial lectures in metallurgy, and received many distinguished service awards. A linguist, he has also lectured in many countries abroad.

During World War II he held key positions, among others, War Production Board, Economic Warfare Branch, FEA, Minerals and Metals Advisory Board. Since the inception of the atomic energy projects he served first the Manhattan Project and later the AEC. As a member of the initial Manhattan Project Committee for world control of atomic energy, he helped draft the classified report that was a technological basis for the Lilienthal and Baruch plans.

His chairmanship of the Engineering Foundation Board, of other professional groups, membership on the MIT Corporation, as well as his numerous committee posts in the AIME and executive posts in Union Carbide over the years emphasize his outstanding combination of scientific and administrative ability. In what may come to be called the "year after Sputnick"—marked by increased government, industry, and professional interest in science and in engineering—the Institute is indeed fortunate to have a man with breadth of interest, thorough scientific background, and administrative ability to guide the Institute during the coming year.

—R. A. Beals

Honorary Members

(Continued from page 137)

bership on the board of regents of the University of California, at which he had been dean of the College of Engineering.

Champion Herbert Mathewson was born in Essex, Conn., in 1881. He received a Ph.B degree from Yale University, M.A. and Ph.D. from Goettingen, and an honorary D.Sc. from Yale University. He began his teaching career as an assistant instructor in chemistry at Massachusetts Institute of Technology, later becoming an instructor, before joining the faculty of Yale University in 1907. At Yale, Dr. Mathewson was, successively, instructor, assistant professor of metallurgy and metallography. He became emeritus professor in 1950, a post he still holds.

Dr. Mathewson has served as a metallurgical consultant at various time for such concerns as The New Jersey Zinc Co., the Scovill Mfg. Co., the Chase Copper and Brass Co., and Bell Telphone Laboratories. In addition, he has been a member of such Governmental boards as the Nonferrous Metallurgical Advisory Board of the Ordnance Dept. operating at the Frankford Arsenal.

His services to AIME have been legion—Chairman of the Institute of Metals Division, Institute of Metals Lecturer, and President of AIME in 1943. In honor of Dr. Mathewson, a Gold Medal award was established by the Institute to surplant the former Certificate of Award granted annually by the AIME Institute of Metals Division for meritorious research publication. He received the James Douglas Gold Medal in 1932.

Dr. Mathewson's professional activities include, in addition to AIME, membership in ASM, serving as Campbell Memorial Lecturer in 1943 and receiving the Gold Medal of the society in 1947. His service on many technical committees of chemical and engineering societies included chairmanship of the Committee B-5 of ASTM on Copper and Copper Alloys. He has been associate editor of Scientific and Technologic Monographs of the Amer. Chemical Soc. and is currently editor-in-chief of a forthcoming monograph on zinc to be published as part of the chemical society's monograph series.

Dr. Mathewson has been instrumental in introducing metallographic techniques to the American nonferrous metal industry and in the education of physical metallurgists in the first half of the present century.

Fred Searls, Jr. was born in Nevada City, Calif., in 1888, and graduated from the College of Mining of the University of California in 1909. For a brief time he was an instructor in mineralogy at the University of California under Professor Andrew C. Lawson, before joining Goldfield Consolidated in Nevada as a geologist. During the years prior to World War I, when he served in France with the U. S. Army, he was geologist or consultant for various mining companies—Goldfield Consolidated, Mason Valley Mines, Mines Co. of America, and New York Orient Mines. His work took him to South Africa, Yunnan, and the East Indias, as well as the U. S.

In the early 1920's Mr. Searls returned to consulting geological work with W. A. Clark, Newmont Mining Corp., and U. S. Smelting, Refining & Mining Co. At that time he was also engaged in apex litigation in Butte, Mont., the Coeur d'Alenes, and elsewhere.

In 1925 he joined Newmont Mining Corp. as vice president, becoming president in 1947 and chairman of the board in 1954.

F. SEARLS, JR.

He again served his country during World War II, first with the Ordnance Div. of the War Dept., War Shipping Administration, and War Production Board, and later as special assistant to the Secretary of State. Mr. Searls was also a member of the U. S. delegation to the UN Atomic Energy Commission and served in the Office of Defense Mobilization.

Mr. Searls' achievements in the fields of geology and public service have won him many honors. In 1946 he received the AIME William Saunders Gold Medal and in 1947 the Medal of Merit of the U. S. Government. He is also the holder of the Moroccan "Order du Ouissam Alaouite Cherifien."

In addition to AIME, Mr. Searls is a member of the Geological Soc. of America, the Mining and Metallurgical Soc. of America, and the Society of Economic Geologists.

The new Honorary Members of AIME will be guests at the Annual Banquet on February 19 during the Annual Meeting in New York. At that time they will each receive an engrossed certificate from the Institute.

Education Symposium

(Continued from page 137)

avoid the setting of minimum standards, and not put engineering education into a straight jacket. The individual curricula and not the college or university is accredited. The accreditation is done on the basis of periodic visits by a committee composed of qualified individuals. The committee has no definite check list upon which to base their decisions. The judgment of the committee is based on the qualitative information obtained from the faculty and on quantitive data furnished by the administrative of the institution. The accreditation committees encourage experimentation in teaching and curricula.

"Professors Newman Hall and R. G. Folsom presented a skit to illustrate mechanics and problems involved in accreditation. It was apparent that considerable thought and deliberation went into the committee's work. There are many facets of teaching and administration which the committee investigates.

"It was demonstrated how the committee obtains its information and what it is looking for. It is not officially stated, but they rate the curriculum on the qualifications of the faculty. From the interviews with the faculty, the examination of course content, student papers, and examination papers, it is judged what the faculty wants to accomplish and what it accomplished with the student.

"My impression of the seminar was that it was a worthwhile attempt. It aroused considerable interest by people in industry in engineering accreditation. Of the 68 in attendance, about two thirds were from industry and the remainder from educational institutions."

In addition to the events covered by Mr. Lazar in his report, there was a specially conducted tour of the General Motors Technical Center, at which the Symposium was held on the first day. C. H. Linder, vice president-engineering services, General Electric Co., was the principal speaker at the dinner that evening. Mr. Linder's comments on and suggestions about the future in engineering education were timely.

On November 8 two panel discussions were held at the Rackham Memorial Building in the quarters of the Engineering Soc. of Detroit. D. A. Ver Planck, Carnegie Institute

of Technology, and Edward McHugh, Clarkson College of Technology, were the moderators. The first panel gave seminar participants an opportunity to question panel members about specific facets of the accrediting program. *Trends in Mechanical Engineering Curricula*, the second panel topic, lead to a spirited "give-and-take" discussion among the industrial people attending, as well as the educators present, giving recognition to the stake of industry in shaping future educational programs.

Welcoming Luncheon Speaker

D. W. BRONK

Detlev W. Bronk will be the featured speaker at the Welcoming Luncheon held on Monday, February 17, at the Sheraton-McAlpin Hotel, during the Annual Meeting.

Although trained originally as an engineer, Dr. Bronk took his Ph.D. degree at the University of Mich. in physics and physiology. He is listed in *American Men of Science* as a physiologist and biophysicist.

A native New Yorker, Dr. Bronk is currently president of the Rockefeller Inst., New York City, president of the Nat'l Academy of Sciences, chairman of the Nat'l Science Board, Nat'l Science Foundation, vice chairman of the Nat'l Advisory Committee for Aeronautics, and a member, President's Science Advisory Committee.

Dr. Bronk is a trustee of John Hopkins University, University of Penn., Rockefeller Foundation, Rockefeller Brothers Fund, and many other institutions. He is also a foreign member of the Royal Soc. of London, the French Academy of Sciences, and of the Royal Danish Soc. of Sciences and Letters.

Dr. Bronk has served as president of John Hopkins University from 1949 to 1953, director of the Johnson Research Foundation for Medical Physics, University of Penn., from 1929 to 1949, and was president, American Assoc. for the Advancement of Science in 1952.

Huggins To Receive Hardy Medal

Dr. Robert Alan Huggins of Stanford University, Stanford, Calif., has been selected to receive the Robert Lansing Hardy Gold Medal of the AIME for 1958. The award recognizes exceptional promise, rather than achievement, in the field of metallurgy, and is given to a metallurgist who has not reached his 30th birthday before the end of the calendar year during which selection of the recipient is made. The award was established in 1956 by Arthur C. Hardy of Cambridge, Mass. as a memorial to his son. It is planned that the AIME San Francisco Section will make the presentation of the medal to Dr. Huggins.

An assistant professor of metallurgy at Stanford University since 1954, Dr. Huggins received his B.A. in Physics from Amherst College, Amherst, Mass. in 1950, his S.M. in Metallurgy from Massachusetts Institute of Technology in 1952, and his Sc.D. in Metallurgy from MIT in 1954. Prior to joining Stanford, he served as an instructor in metallurgy at MIT. The author of several technical papers and an active member of numerous professional societies, Dr. Huggins has been honored with the Walker Mathematics Prize, Amherst College, in 1946 and was the recipient of the Welding Research Council Fellowship, MIT, from 1951 to 1953.

This year's Award winner is married and has three children. Sailing is his hobby. Last summer he won second place in the National Championship Regatta, Snipe Class, at Peoria, Ill.

The Robert Lansing Hardy Gold Medal was awarded last year to D. W. Fuerstenau of the Niagara Frontier Section. He was the first recipient of this award.

Col. Patterson Is All Institute Technical Session Speaker

This year's All-Institute Technical Session Speaker will be Col. Charles G. Patterson, Chief of the Department of the Army Staff, Army Ballistic Missile Agency, Redstone Arsenal, Huntsville, Ala. He will deliver his talk entitled, *Push Buttons in Modern Warfare*, at the All-Institute Technical Session held in the Grand Ballroom of the Statler Hotel on Tuesday, February 18.

Col. Patterson is a graduate of the U. S. Military Academy. He came to the Army Ballistic Missile Agency from Fort Monroe, Va., where he was stationed at the headquarters of the Continental Army Command as chief of the doctrine and requirement div. in G-3.

Col. Patterson holds a B.S. degree in engineering from USMA and diplomas from Coast Artillery School, Armed Forces Staff College, and National War College. He is a member of the Assoc. of Graduates, USMA, Assoc. of U. S. Army, and Fishing Club of America.

COL. C. G. PATTERSON

Col. Patterson is an enthusiastic fisherman who finds little time at present to enjoy this sport. Some of his other hobbies are fly-tying (making artificial flys to be used in fly-fishing), hunting, and photography.

Prior to becoming an active member of the Nation's armed forces, Col. Patterson was employed by the Interstate Trust Co. in New York.

He has served several overseas tours of duty and has earned the Legion of Merit, Bronze Star Medal, Army Commendation Ribbon, French Legion of Honor, French Croix de Guerre with two palms, and Luxemburg Courrone de Chene.

Alaska Is Topic Of Annual Dinner Speech

My Alaska Adventures will be the topic of Harold Eide, speaker at the Metallurgical Society's Annual Dinner held in the Ballroom of the Sheraton-McAlpin Hotel on Tuesday evening, February 18. During his talk, he will recount the personal story of his years prospecting for riches, from the Arctic sea's to Mexico. Hailing from northern Norway, Mr. Eide has spent many years in Alaska, where he arrived from his native land toward the end of the Big Gold Rush.

Manpower Symposium

During the AIME Annual Meeting in New York, the Metallurgical Society's Education Committee and the Committee on the Metallurgical Profession will feature a *Metallurgical Manpower Symposium* on Sunday afternoon, Feb. 16, 1958, at the Hotel Sheraton-McAlpin. Associate chairmen for the conference are Morris Cohen and David Swan.

The topic, *Scientific Brainpower: Are We Solving the Problem?* will be discussed by Howard A. Myerhoff,

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Left: Scene of the Annual Dinner held at the Ballroom of the Penn-Sheraton Hotel, Pittsburgh, showing the head table. Right: The speaker of the evening, Edward A. Livingstone, vice president, Babcock & Wilcox Co., Beaver Falls, Pa. His talk, *The Atomic Age Challenge To Steel*, is found on page 111.

Record Attendance At Annual Electric Furnace Conference

In spite of snow and rain, the Fifteenth Annual Electric Furnace Conference broke all previous attendance records with 1070 registrants.

Those able to arrive on the conference's opening day, Wednesday December 4th, were treated to an all-day visit to the Babcock & Wilcox's Beaver Falls plant. Following lunch, a welcoming message was given by Work's Manager, Paul J. Utnehmer, and V. E. Zang, the conference chairman, expressed thanks to B&W for their hospitality. The plant trip itself was superbly organized with the group of 225 split into a number of smaller groups and driven to the appropriate departments. Covering 550 acres and employing 4200 persons, the plant produces some 16,000 tons of seamless tubular products per month. Seen were the plant's four electric arc furnaces producing ingots which are forged into blooms to be subsequently rolled into bars. The plant is equipped with four piercing mills which produce a wide range of tube sizes. The plant also includes a cold drawing department, an extrusion works, and a shop for producing welded stainless tubing.

Highlights of the technical sessions included a meeting on vacuum melting with an overall summary of the subject, an extensive survey of consumable-electrode vacuum melting, and a paper on induction vacuum melting. A session on refractories included papers on cast sections of furnace roofs, ladle refractories, basic refractories, and furnace bottoms. The foundry practice session included an extensive discussion of spectrographic analysis. One afternoon was devoted to the subject of the economic utilization of power with speakers from utility firms as well as from the electric steel industry itself. The Physical Chemistry of Steelmaking Committee organized a timely session on nitrogen in electric furnace steel.

At the Annual Dinner retiring chairman of the Electric Furnace Steel Committee, D. L. Clark, was thanked for long and faithful service to the Committee by convention chairman V. E. Zang. In appreciation Clark was presented a clock, operated by atmospheric pressure, and, symbolically, designed to operate forever.

Members of the head table at the banquet included AIME President, Grover J. Holt, AIME Secretary, Ernest Kirkendall, Metallurgical Society Vice-President W. R. Hibbard, Jr., and many other distinguished persons. Toastmaster, Stanley M. Norwood, Assistant to the President, and Vice-President, Electro Metallurgical Co., Div. of Union Carbide Corp., entertained dinner guests from his vast collection of humor and introduced the speaker of the evening, Edward A. Livingstone, Vice-President, Babcock & Wilcox Co.

Mr. Livingstone in his talk, "The Atomic Age Challenge to Steel" hurled a big challenge to metallurgists of the electric furnace steel industry, as he went on to say, "The

Shown left to right are: A. C. Ogan, vice chairman of the conference committee; committee chairman, V. E. Zang, the retiring chairman of the Electric Furnace Steel Committee; D. L. Clark; and past chairman, C. E. Sims. Right: D. L. Clark, past chairman, Electric Furnace Steel Committee, recieves a certificate in appreciation for long and faithful service to the Committee, from convention chairman, V. E. Zang.

foremost challenge and one with which we can come most readily to grips—is the demand of nuclear energy applications for products to be applied on the basis of the principle of perfection. . . Another important challenge of the nuclear program lies in the corrosion involved in reactor cooling systems." Many new problems and concepts, such as induced radioactivity and neutron absorption cross-section, must be faced.

"The problems of tomorrow are incomprehensible in the light of the knowledge of today." But, Mr. Livingstone, concluded, "I am sure steel will equal to the challenge of the Atomic Age, whether that challenge requires new solutions to old problems or calls for fresh approaches to new problems with new materials and new manufacturing techniques."

The Fifteenth Annual Electric Furnace Steel Conference can be considered to have been a complete success from every standpoint, thanks in large measure to C. E. Ahl, Jr. and his Local Committee on Arrangements.

Manpower Symposium

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executive director, Scientific Manpower Commission. The report of the Special Committee on Manpower for the Metallurgical and Ceramics Professions will take the lead, with the introduction *Committee History and Organization*, given by George A. Roberts, vice president, Vanadium Alloys Steel Co. Walter R. Hibbard, Jr., manager, alloy studies, General Electric Research Laboratories, will speak on *Pre-College Student Awareness of Our Profession*. Following this talk, William E. Mahin, president, Malleable Research & Development Corp., will discuss *Adult Awareness of Our Profession: A Proposed Scholarship Program*. The concluding talk, *Program for Action: The Metallurgy-Ceramics Foundation*, will be presented by George A. Roberts, vice president, Vanadium Alloys Steel Co.

Third Reactive Metals Conference Prepares To Convene in May

The Hotel Statler will open it's doors to the Third Reactive Metals Conference to be launched in Buffalo, May 27 to 29, 1958, under the sponsorship of the Niagara Frontier Section of AIME. The point of issue will be on those metals which, by present standards are difficult to process by conventional means, due to their reactivity with the more common refractories—oxygen or nitrogen.

Various technical sessions will hold discussions on the production, properties, fabrication, and application of tantalum, niobium, titanium, zirconium, hafnium, vanadium, molybdenum, tungsten, thorium and uranium, and their alloys.

Outstanding evening events to windup each day's sessions are on the bill. One night will be devoted to a panel discussion on the future of reactive metals, and another evening will feature a Fellowship Hour and Banquet, at which the delegates will be addressed by a speaker of national reputation.

An exhibition pertinent to the entire field of reactive metals will be on display at the Statler Hotel during the Conference.

The General Chairman for the meeting is S. F. Urban, Titanium Alloy Manufacturing Div., National Lead Co. Other members of the Conference Committee are: Administration, J. D. Roach; Arrangements, E. L. Gielzen; Exhibits, R. K. Kulp; Finance, W. W. Stephens; Plant Visitations, C. Fogel; Program, W. Clough; Publicity, C. W. F. Jacobs; and Registration, C. H. Emery.

News of EDUCATION

► Competition for the 1958 to 1959 Henry Krumb scholarships in the School of Mines at Columbia University, New York, N. Y., was recently announced.

Open to candidates for degrees in mining, mineral, and metallurgical engineering at Columbia, the scholarships have a value of $1500 per year, plus traveling expenses to New York City from the students home. Up to six awards are made each year, based solely on the high school and college performance records of applicants.

The scholarships are supported by a fund established at Columbia in 1945 by Henry Krumb, noted mining engineer and mining consultant, who is a member of the University's engineering class of 1898.

Malcolm E. Wane, an associate in mining at Columbia and chairman of the Krumb Scholarship committee, has advised that applications for the awards may be made through mid-February to the Office of University Admissions, from which application forms and further information may be obtained. Announcement of the recipients of the scholarships is made in March.

► Scholarship aid totaling $557,682 during the 1957 to 1958 academic year at Lehigh University, Bethlehem, Pa., was recently announced. Dr. Wray H. Congdon, dean of students, reported that $381,282 has been awarded to 458 undergraduates in the three colleges of the university for this academic year. In the graduate school, $176,400 has been allocated to students working for master's and doctorate degrees.

The average scholarship award for 1957 was $734. Included in the grants are 88 which are supported by the business and industrial firms.

Scholarship aid by classes is evenly divided. Of the total, 112 seniors are receiving $92,765; a similar number of juniors are receiving $91,615; 140 sophomores are getting $96,995, and aid to the freshman class totals $99,907 to 126 students.

► The establishment of the Frank Breckenridge Bell Memorial Scholarship at Lehigh University by Edgewater Steel Charitable Trust Committee of Pittsburgh has recently been announced. The award presented by Davitt S. Bell, chairman for the donors, is in memory of Frank B. Bell, a mechanical engineering graduate in 1897 from Lehigh and a trustee of the university from 1936 to 1949.

The first award of $1000 is to be made this year by the university's committee on scholarships and loans.

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AROUND THE SECTIONS

• The November meeting of the **Montana Section** was held in the Montana Room of the Rainbow Hotel, Great Falls, Mont., on Nov. 23, 1957. A cocktail hour and roast-beef dinner was provided through the courtesy of the Anaconda Co., Great Falls. The featured speaker was Charles De Armond, superintendent of the zinc leaching department of the Great Falls Reduction Plant, Anaconda Co., who discussed *Recent Improvements at the Great Falls Zinc Plant.*

• The **Southwestern Section, NOHC,** is holding its February meeting with a cocktail hour and fellowship dinner at the Lennox Hotel in St. Louis on February 7. At the Dec. 2, 1957, meeting of the Section's executive board at the Lennox Hotel, St. Louis, George Grosvenor was appointed to complete the unexpired term of chairman upon acceptance of the resignation of K. P. Campbell. Other newly appointed officers are: Levi D. Yager, vice chairman; Norvall M. Huntausen, secretary-treasurer; Harry J. Hausner, assistant secretary-treasurer; and S. L. Fredericks, chairman of the membership committee.

• A joint meeting was held by the **El Paso Section** with the El Paso Section of AIEE at the Hotel Cortez in El Paso, Texas. James H. Wright, Atomic Power Div., Westinghouse Electric Corp., Pittsburg, gave a talk on *The Utilization of Atomic Power in Industry.* The name of the section has been changed from the El Paso Metals Section, to the El Paso Section by a unanimous vote.

The Leading Role, **produced by the Formed Steel Tube Institute, 850 Hanna Bldg., Cleveland 15, Ohio, is a new 16-mm, sound film with a running time of 25-min., showing the manufacture of welded steel tubing and numerous applications of tubing. It is available free for showing to company personnel, and interested engineering and purchasing organizations and is of special interest to designers, specification writers, production men and buyers in the metal-working industries. A booklet,** *The Leading Role,* **based on the movie is available from the Institute upon request. Direct film loan requests to Modern Talking Picture Service, 3 E. 54 St., New York 22, N. Y.**

"For instance, right now, do you think the Russians are fooling around with a regional get-together of metallurgical engineers?"

Drawing by Dedini,
© 1957 The New Yorker Magazine, Inc.

Education

(Continued from page 143)

This is the second scholarship established at Lehigh in tribute to Mr. Bell, founder of Edgewater Steel Co., who died in 1949.

Lehigh University also received a gift of $8400 from the board of directors of Bethlehem Fabricators Inc. The Bethlehem Fabricators Scholarship Fund was established in 1950 and is one of two permanent funds given to the university by the company in addition to their many gifts for other purposes.

The second fund of $30,000, known as the Award of Bethlehem Fabricators Inc., was established in 1952 in honor of the late R. P. Hutchinson, then chairman of the board of directors in recognition of his forty years of service with the concern.

Recipients of the Award of Bethlehem Fabricators Inc., are selected from the senior class by the university's committee on scholarships and loans. They are chosen on the basis of initiative, ability, industry and scholastic achievement during their sophomore and junior years.

► Grants totaling nearly $1,150,000 have been awarded to 135 universities and colleges in Du Pont's annual program of aid to education, the company has announced. The total for the next academic year is about $100,000 more than Du Pont contributed for this school year.

Most of the increase and more than half of the entire program are grants to colleges and universities for strengthening the education of scientists and engineers. These grants will support the teaching of science and mathematics as well as other subjects. At the same time, grants for fundamental research are being continued, as are grants for fellowships, which once made up the entire plan. Du Pont's program dates from 1918.

Du Pont's grants for advancing teaching, which proved effective in science, mathematics, and other liberal arts courses, are now being extended to medical schools for the first time.

The grants for the teaching total about $664,000 in awards to more than 100 privately controlled colleges and universities, including 12 medical schools. The aid to fundamental research totals $309,000 and includes, in large part: 1) $15,000 each to ten universities and $10,000 each to ten others for fundamental research of their own choosing in chemistry. 2) $1500 each to 26 universities to enable individual staff members to undertake summer research of their own choosing in chemistry or chemical engineering. The postgraduate fellowships are $155,000 for 40 fellowships in science and engineering to be shared by 25 universities.

PERSONALS

Tasuku Fuwa is now serving with the department of metallurgy, Tohoku University, Sendai, Japan. He was formerly associated with Massachusetts Institute of Technology, Cambridge, Mass.

Clarence Zener, director of the Westinghouse Research Laboratories, Pittsburgh, has been awarded the Bingham Medal of the Soc. of Rheology for his research with metals. An international authority on the elastic behavior of metals, Dr. Zener was cited "for his important work on the viscoelastic behavior of metals." The award was presented to him at the annual meeting of the society at Princeton, N.J.

F. D. Rosi was recently appointed head of semiconductor and electrochemical research at RCA Laboratories, Princeton, N. J.

Lieh-Leng C. Cheng is now located with the Nuffield Research Group, Royal School of Mines, London, England. He previously resided in Chicago.

Robert Bakish has resigned his position as senior metallurigst in charge of the Metallurgy Laboratory at Sprague Electric Co., N. Adams, Mass. and has accepted a position as staff metallurgist with Ciba Ltd., Basel, Switzerland. His new duties entail the organization and supervision of a physical metallurgy section in the Rare Metals Div. of Ciba.

Sheldon Weinig, formerly assistant professor of metallurgy, College of Engineering, New York University, has been elected president of the newly formed Materials Research Corp., Yonkers, N. Y., which provides research and development services for industry and government.

James Howell Smith was recently promoted to Major in the Chemical Corps., U. S. Army Reserve. Mr. Smith represents the Chemical-Pigments-Metals Div. of the Glidden Co., Cleveland.

Albert R. Kaufmann, no longer associated with the Massachusetts Institute of Technology, Cambridge, Mass., is now employed as technical director for Nuclear Metals Inc., Cambridge, Mass.

H. Howe has joined the African staff of his company, Ashmore, Benson, Pease & Co. Africa (Ptg.) Ltd., Johannesburg, South Africa.

William J. Kroll was the recipient of one of the highest awards in the American industrial chemistry, the Perkin Medal of the American Section of the Soc. of Chemical Industry. He received the medal at a dinner in his honor on January 1 at the Waldorf Astoria Hotel, New York. Dr. Kroll is consulting electrochemist and metallurgist of Corvallis, Ore., and is the developer of the basic Kroll process for producing titanium and zirconium metal.

T. F. Kaveney is now associated with the sales department of Electro Metallurgical Co., Div. of Union Carbide Corp., Cleveland. He has been assigned to the electric furnace section of the Metallurgical Service Div. Prior to his new undertaking, he was a metallurgist for Northeastern Steel Corp., Bridgeport, Conn.

The *whale award* of the Investment Casting Institute, Chicago, which symbolizes a *whale of a job* done by its recipients, was recently awarded to two men at the fifth annual meeting of the Institute in Chicago. **Vincent S. Lazzara,** president of Casting Engineers of Chicago, received the *whale* for his "devotion to the Institute since its inception." **Richard A. Flinn** of the University of Michigan was also honored for his liaison work between the Institute and the Universities in the dissemination of educational information on the investment casting process.

Robert W. Stollstorff was recently separated from the Armed Forces and is now employed at the research laboratory of Lindberg Engineering Co., Chicago.

Leland H. Grenell has accepted a position with The Stolle Corp., Sidney, Ohio, as assistant to the president for development.

D. Swan has been appointed director of research for the Linde Co., division of Union Carbide Corp., New York.

R. L. Clark, previously staff engineer, blast furnaces, for U. S. Steel Corp., Pittsburgh, is now affiliated with Koppers Co. Inc., Pittsburgh, as chief engineer, Chilean Operations, in the Engineering and Construction Div.

Barton M. Silverman, formerly with the Missile and Ordnance Systems Dept., General Electric Co., Philadelphia, is now serving with the Beryllium Corp., Reading, Pa., as a metallurgical engineer.

Bryce N. Logan is now associated with Kerr McGee Nuclear Fuels, Golden, Colo. He was previously with the National Lead Co. Inc., Monticello, Utah.

E. W. Casewell has resigned his post at Earle Bourne & Co. Ltd., Birmingham, England, and is now engaged at Hereford County Technical College, England.

The National Carbon Co., division of Union Carbide Corp., New York, recently announced new personnel assignments in its electrode products organization. **James King, Jr.,** formerly central division manager, electrode products sales, Chicago, has been named sales manager, New York. **John M. Schreiner,** previously Pacific division manager, San Francisco, has been named central division manager, Chicago, **M. M. Rand,** formerly electrode products representative in Detroit, has been appointed Pacific division manager of electrode product sales.

Doyle Geiselman and **Arnold E. Hultquist** have joined the staff of the Metals Research Laboratories of Electro Metallurgical Co., division of Union Carbide Corp., Niagara Falls, N. Y. Mr. Hultquist is now serving the Chemicals Research Group as an assistant chemist, and Dr. Geiselman has been assigned to the Metals Research Group as a research metallurgist.

J. C. Whetzel has been appointed manager of tin plate products for U.S. Steel Corp., Pittsburgh. He was formerly assistant manager of tin plate products for the company.

E. Epremian, formerly chief, metallurgy and materials branch, U.S. Atomic Energy Commission, Washington, D.C. has joined the Metals Research Laboratories of Electron Metallurgical Co., division of Union Carbide Corp., Niagara Falls, N.Y.

Stuart T. Ross has been appointed head of the Metallurgical Research Dept., Engineering Div., Chrysler Corp., Detroit. He was previously laboratory supervisor of that department.

Robert H. Forsyth was recently transferred from the Babcock & Wilcox Co., Pittsburgh, to the company's Chicago office.

Frank R. Palmer, president of The Carpenter Steel Co., Reading, Pa., has been named president of the company's newly acquired Northwestern Steel Corp., Bridgeport, Conn. Seven other officers were also named to head up the new subsidiary, now officially known as Carpenter Steel of New England Inc. They are: **John Moxon,** executive vice president; **Arlington A. Britton Jr.,** vice president-production; **H. Sturges Potter,** vice president-sales; **Carl B. Post,** vice president and technical director; **Willard E. Roberts,** secretary and treasurer; **Oliver May,** assistant treasurer and assistant secretary; and **William Bouton,** controller. All except May and Bouton hold similar positions with the parent firm.

Guy Waddington was recently appointed as director of the office of critical tables in the division of chemistry and chemical technology for the National Research Council, National Academy of Sciences, Wash-

(Continued on page 146)

Personals

(Continued from page 145)

ington, D. C. Prior to his appointment, Dr. Waddington was chief of the Branch of Thermodynamics, Bureau of Mines, Petroleum Experiment Station, Bartlesville, Okla. He is also director of the recently activated API Research Project 52C.

Grover J. Holt, AIME President, has been appointed to assistant to the president for Cleveland-Cliffs Iron Co., Ishpeming, Mich. He has been general manager of the company.

Henry P. Kirchner, previously associated with the Corning Glass Works, Corning, N.Y., is now employed by Cornell Aeronautical Laboratory Inc., Buffalo.

J. Roy Gordon was recently elected to the Board of Directors of The Babcock & Wilcox Co., New York. He is executive vice president, a director, and a member of the executive committee of the International Nickel Co. of Canada Ltd., and is executive vice president and director of International Co. Inc.

Amos J. Shaler, professor and head of the metallurgy department, Pennsylvania State University, University Park, Pa., is the 1957 winner of the annual $2000 Metallurgy Teaching Award, given by the American Soc. for Metals for the best teaching performance on the part of a young instructor or professor in this engineering curriculum.

J. Scott Parrish, Jr., president, Richmond Foundry & Mfg. Co. Inc., Richmond, Va., was recently re-elected president of the Grey Iron Founders' Soc. at its 29th annual meeting in Chicago. Also re-elected at the convention were: **A. M. Nutter,** treasurer, E. L. LeBaron Foundry Co., Brockton, Mass., and the incumbent vice president; and **A. H. Renfrow,** partner, general manager, Renfrow Foundry, Los Angeles, secretary. **C. R. Garland,** The W. O. Larson Foundry Co., Grafton, Ohio, was named treasurer. Four new members of the board of directors elected for a three year term are: **W. G. Butler,** accountant, Golden Foundry Co. Inc., Columbus, Ind.; **R. Mayo Crawford,** vice president, The Turner & Seymour Mfg. Co., Torrington, Conn.; **J. Douglas James,** vice president and general manager, Urick Foundry Co., Erie, Pa.; and **R. W. Wilder,** secretary, Elkhart Foundry & Machine Co., Elkhart, Ind. **D. H. Workman,** the Society's executive vice president, was re-appointed.

R. E. Hadady has been appointed to the newly created post of sales manager for DataTape products, Consolidated Electrodynamics Corp., Pasadena, Calif. Hadady formerly was in charge of a special company project which produced magnetic-tape instrumentation for testing of intercontinental ballistic missiles at Patrick Air Force Base, Fla.

John von Rosen, who has been director of plant engineering for Chrysler Corp., Detroit, was recently named director of manufacturing engineering for the company. In his new capacity, he will be in charge of the corporation's production, industrial and plant engineering.

Robert H. Forsyth, previously sales engineer for the Babcock & Wilcox Co., Pittsburgh, has been appointed manager of the company's Chicago district sales office, refractories div.

Hermann P. Good, division manager, Textile Machine Works, Reading, Pa., was the recipient of the Gold Medal for outstanding service to the association and the industry; this is the highest award of the Grey Iron Founders' Soc., Cleveland. The presentation was made at the Society's 29th annual meeting at the Drake Hotel, Chicago.

Lester C. Hill was recently appointed assistant sales manager for the Pittsburgh Crucible Steel Co. of America. He formerly served as sales manager with the Vulcan Crucible Steel Div., H. K. Porter Co. Inc., Aliquippa, Pa.

James L. McGinnis, previously assistant district sales manager for Allegheny Ludlum Steel Corp., St. Louis, has been promoted to St. Louis district sales manager for the company.

Four appointments to key positions in the metallurgical department of the Babcock & Wilcox Co.'s Tubular Products Div., Beaver Falls, Pa., were recently announced. **John F. Beck** has been named metallurgist supervisor of technical service. **Clark P. Church** has become metallurgist supervisor of process development. **John F. Ewing** has been appointed metallurgist supervisor of research, and **Thomas M. Krebs** has been made metallurgist supervisor of customer service.

Industrial sales of Basic Inc., Cleveland, recently announced the appointment of **Richard E. Wyman** and **William G. Winters** to the company's sales and service staff. Wyman will be located in the Hammond, Ind., office and Winters will serve in the central region with headquarters in Cleveland.

Robert L. Swank has been promoted to manager of sales—plastic pipe for National Tube Div. of U. S. Steel, Pittsburgh. He was formerly a resident salesman in Des Moines, Iowa, for the Corp.'s Chicago district sales office.

OBITUARIES

Erle Victor Daveler

An Appreciation by
Andrew Fletcher

Erle Victor Daveler, known to thousands of mining men and one of the Nation's most distinguished mining engineers, died at his home in New York City on Nov. 11, 1957, at the age of seventy-two. No words of mine can express the sense of loss which his many friends feel at Erle Daveler's passing. The Institute has lost one of its greatest champions.

Erle Victor Daveler was born in Denver, Colo., on Dec. 31, 1885, and educated at the University of California from which he graduated in 1907. In 1918 he received the degree of metallurgical engineer and was honored by his university in 1947 by being awarded an LL.D.

He began his career in Tonopah, Nev., in 1907 and then moved to the Utah Copper Co. There he engaged in research from 1909 to 1911. He then became assistant superintendent of mills for the Ray Consolidated Copper Co., and for five years was superintendent of mills and assistant manager of the Alaska Gold Mines. He then moved again; this time to Butte to become general superintendent and finally, general manager of the Butte & Superior Co. His steady rise upward led him to vice president, treasurer and director of the Nevada Consolidated Copper Corp., Utah Copper Co., Bingham & Garfield R.R. Co., Ray & Gila Valley R.R. Co., Gallup American Coal Co., Nevada Northern R.R. Co.—all affiliated with the Jackling interests then so active in developing the low-grade copper resources of the West.

He severed connection with the Kennecott organization in 1943 and moved to New York to become a vice president and director of the American Zinc, Lead, & Smelting Co. His talents had, by this time, spread so broadly over the mineral activities of the Nation that he ultimately found himself also president and director of the Mesabi Iron Co., developing the low-grade iron resources of Minnesota, an office he held at the time of his death. In addition, he became chairman of the executive committee of the Lone Star Cement Corp. His directorships comprised representation on the boards of the Cuban Atlantic Sugar Co., Granite City Steel Co., and Texas Gulf Sulphur Co.

Erle Daveler did not neglect his fellow man. He engaged in many philanthropic activities worthy of record. He became, upon the death of Charles Hayden, a trustee of the Charles Hayden Foundation which has done so much for the boy's clubs

of the country. As a trustee of the Stevens Institute of Technology and a member of the Montana Board of Education, he signified his deep interest in educational problems. Besides being a member of the AIME, he was a past president of the Mining and Metallurgical Society of America and a member of many clubs.

Perhaps the outstanding quality of which Erle Daveler possessed was his ability to be completely realistic about any problem he faced. He always sought to look at facts squarely, to make certain that any action taken would not prove to be a source of subsequent keen regret. He never sought for expedience, but strove for permanent sound progress, whether it was for the benefit of the many corporations he served, or for the continued growth and prosperity of the Institute. Erle was a wonderful companion—in business or at the bridge table. His warm and friendly personality, as well as his characteristic good judgment, will be keenly missed by all of us who knew and loved him.

Joseph J. White (Member 1940) passed away on October 20, 1957. Born in Uniontown, Ala., he was educated at Tennessee Military Institute, U. S. Naval Academy, and Renssalaer Polytechnical Institute, receiving a B.S. in metallurgical engineering. At the time of his death, Mr. White was serving with the Erie Forge & Steel Corp., Erie, Pa.

C. F. Brenthel (Member 1953) died in Nurnberg, Germany on May 5, 1957. Born in Leipzig, Germany on June 19, 1891, he graduated from the Mining Academy in Freiberg, Germany with a degree in metallurgical engineering.

John H. Vohr (Member 1947) passed away on Dec. 1, 1957 in Gary, Ind., at the age of sixty-four. He was born in Pittsburgh and attended Cornell University, receiving a degree in mining engineering in 1916. At the time of his death, Mr. Vohr was working as general superintendent of U. S. Steel's Gary Steel Works.

W. R. Phibbs (Member 1913) died on May 24, 1957. Born in Nilia, Ohio in 1881, he resided in Youngstown, Ohio at the time of his death.

Karl Nibecker (Member 1914) passed away on May 11, 1957. Born in Sockonorett, R. I., in 1886, he graduated from the University of Pennsylvania in 1907 with a B.S. degree in mining engineering. In 1910 he was awarded his M.E. degree from the same university. At the time of Mr. Nibecker's passing, he was president of Imperial Type Metal Co., Philadelphia, Pa.

K. H. Moody (Associate Member 1954) died June 5, 1957. He was born in Fargo, N. Dakota on Jan. 10, 1905 and had served as director, superintendent, open hearth, American Steel & Wire Div., U. S. Steel Corp., in Duluth, Minn. at the time of his death.

Cecil Farrow (Associate Member 1954) passed away on Nov. 22, 1957. He was born in Brant County, Ontario, Canada, on May 4, 1898, and was associated with Republic Steel Corp. in Cleveland at the time of his death.

J. P. Dick (Member 1926) died recently. He was born on Oct. 26, 1903 in Bolton, Ontario, Canada and was educated at the University of Toronto, Canada. At the time of his passing, he was serving the Magnesium Co. of Canada, Montreal, Canada.

MEMBERSHIP

Proposed for Membership
Metallurgical Society of AIME

Total AIME membership on Dec. 31, 1957, was 28,823; in addition 3,974 Student Members were enrolled.

ADMISSIONS COMMITTEE

Harold K. Work, Chairman; Francis B. Foley; T. D. Jones; E. S. Machlin; J. H. Scaff; Paul Von Stein; T. B. Winkler.

The Institute desires to extend its privileges to every person to whom it can be of service, but does not desire as members persons who are unqualified. Institute members are urged to review this list as soon as possible and immediately to inform the Secretary's office if names of people are found who are known to be unqualified for AIME membership.

Members

A. D. Allen, Lively, Ont., Can.
Dimitri Argyriades, Pittsburgh
William J. Collins, Corning, N. Y.
W. G. Forster, Youngstown, Ohio
L. Mark Irwin, Minneapolis, Minn.
William C. Jack, Butler, Pa.
William V. Johnston, Schenectady, N. Y.
James W. Poynter, Dayton, Ohio
Shozo Yoshioka, Sakia City, Osaka, Japan

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H. Z. Babbitt, Rapid City, S. Dak.
Peter Morrison, San Francisco
Arthur M. Schwarz, Calumet City, Ill.

Junior Members

George C. Barnes, East Chicago, Ind.
John Peter Douglas, Calumet City, Ill.
Gustavo A. Herrera, Helena, Mont.
John T. McAllister, Pittsburgh
Arthur T. Morgan, East Chicago, Ind.
Joseph A. Morgan, Monaca, Pa.
James L. Munson, East Chicago, Ind.
Charles W. Rainger, Sandusky, Ohio
M. I. Ritchie, Riverton, Wyo.
Norman A. Robins, Markham, Ill.
K. S. Sharma, Chicago
Roger W. Staehle, Arlington, Va.
C. M. Wayman, Urbana, Ill.

REINSTATEMENTS—CHANGE OF STATUS

Reinstatement to Member

Roy M. Erkandson, Paterson, N. J.

Student to Member

C. Borroughs Gill, Easton, Pa.

NECROLOGY

Date Elected	Name	Date of Death
1937	John C. Askam	July 29, 1957
1919	George Baekeland	Unknown
1953	C. F. Brenthel	May 1957
1901	G. L. Collard Legion of Honor	Unknown
1951	John C. Detweiler	Nov. 15, 1957
1926	J. P. Dick	Unknown
1939	Forest D. Dorn	Unknown
1956	John Drotar, Jr.	Nov. 16, 1957
1954	Cecil Farrow	Nov. 22, 1957
1940	Eugene Fisher	Oct. 10, 1957
1948	Harold L. Gardner	Oct. 22, 1957
1945	R. H. Gwinner	Nov. 18, 1957
1952	William L. Holmes	Aug. 31, 1957
1954	Robert H. Isenberg	Dec. 8, 1957
1934	Augustine B. Kelly	Nov. 20, 1957
1938	William L. Kleitz	Nov. 19, 1957
1921	Ralph E. Larry	Oct. 31, 1957
1915	George C. McFadden	Dec. 1, 1957
1954	K. H. Moody	June 5, 1957
1914	Karl Nibecker	May 11, 1957
1909	J. E. Penberthy	Nov. 14, 1956
1913	W. R. Phibbs	May 24, 1957
1939	John L. Ramsell	Dec. 15, 1957
1948	Earl A. Rinker	April 8, 1957
1935	Herbert A. Sawin	Dec. 2, 1957
1940	Melbert Schwarz	Oct. 13, 1957
1953	A. P. Shepard, III	Feb. 6, 1957
1928	Thomas C. Shotwell	Dec. 13, 1957
1940	J. J. Siegel	Unknown
1956	Harold B. Smith	Unknown
1916	William N. Smith	Mar. 28, 1957
1918	B. H. Stockett	Dec. 23, 1957
1920	M. L. Summers	May 21, 1957
1956	W. J. Swigert	October 1957
1955	Chas. C. Toomey	Nov. 15, 1957
1947	John H. Vohr	Dec. 1, 1957
1940	Jos. J. White, Jr.	Oct. 20, 1957
1950	S. C. Yule	Dec. 15, 1957

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COMING EVENTS

Feb. 2, AIME NOHC Southwestern Section, St. Louis.

Feb. 13, AIME Cleveland Section, Carter Hotel, Cleveland.

Feb. 16-20, AIME Annual Meeting, Statler and Sheraton-McAlpin Hotels, New York.

Mar. 12, AIME NOHC Chicago Section, annual all-day meeting, Del Prado Hotel, Chicago.

Mar. 12, AIME New York Section, Powder Metallurgy Group, Brass Rail Restaurant, New York.

Mar. 17-21, EJC Nuclear Congress, International Amphitheatre, Chicago.

Mar. 20, AIME Cleveland Section, regional symposium, Carter Hotel, Cleveland.

Mar. 25, AIME Connecicut Section, dinner-meeting, Chase Country Club, Waterbury, Conn.

Mar. 27-28, AIME San Francisco Section, St. Francis Hotel, San Francisco.

April 9, AIME San Francisco Section, Engineers' Club of San Francisco.

Apr. 14-16, AIME, 41st National Open Hearth Steel and Blast Furnace, Coke Oven, and Raw Materials Conference, Hotel Statler, Cleveland.

April 23, AIME Niagara Frontier Section, joint meeting with local section, Canadian Institute of Mining and Metallurgical Engineers, Royal Connaught Hotel, Hamilton, Ontario.

May 5-6, AIME, Conference on Properties of High-Strength Steel, Penn-Sheraton Hotel, Pittsburgh.

May 5, 6, AIME High-Temperature Materials Conference, Ambassador Hotel, Los Angeles.

May 12-16, Southwestern Metal Exposition and Congress, State Fair Park, Dallas.

May 27-29, AIME Third Reactive Metals Conference; host section: Niagara Frontier Section; Statler Hotel, Buffalo.

June 6, AIME NOHC Southern Ohio Section, golf outing, Summit Hills Country Club, Fort Mitchell, Ky.

Oct. 3-4, AIME NOHC Southern Ohio Section, fall meeting, Deshler-Hilton Hotel, Columbus, Ohio.

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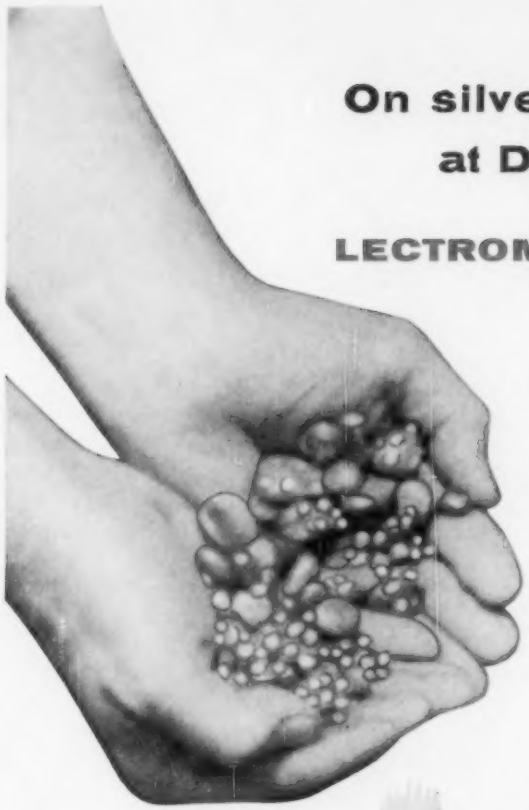
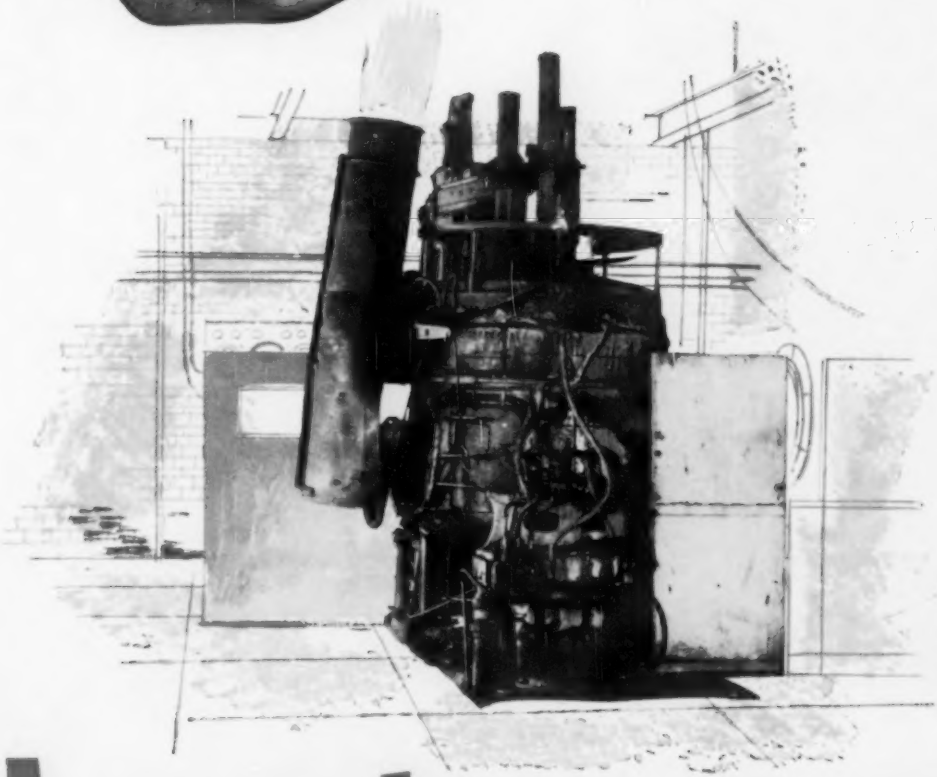


On silver and cobalt production at Deloro Smelting & Refining

LECTROMELT FURNACE EQUIPMENT

Silver is first smelted from the ore with Lectromelt furnace equipment at Deloro Smelting & Refining Company, Deloro, Ontario. Metallic cobalt is produced in a blast furnace, then melted in this 800 kva Lectromelt furnace to produce cobalt shot.

For data on melting and smelting furnaces, write Lectromelt Furnace Division, McGraw-Edison Company, 326 32nd St., Pittsburgh 30, Pennsylvania.



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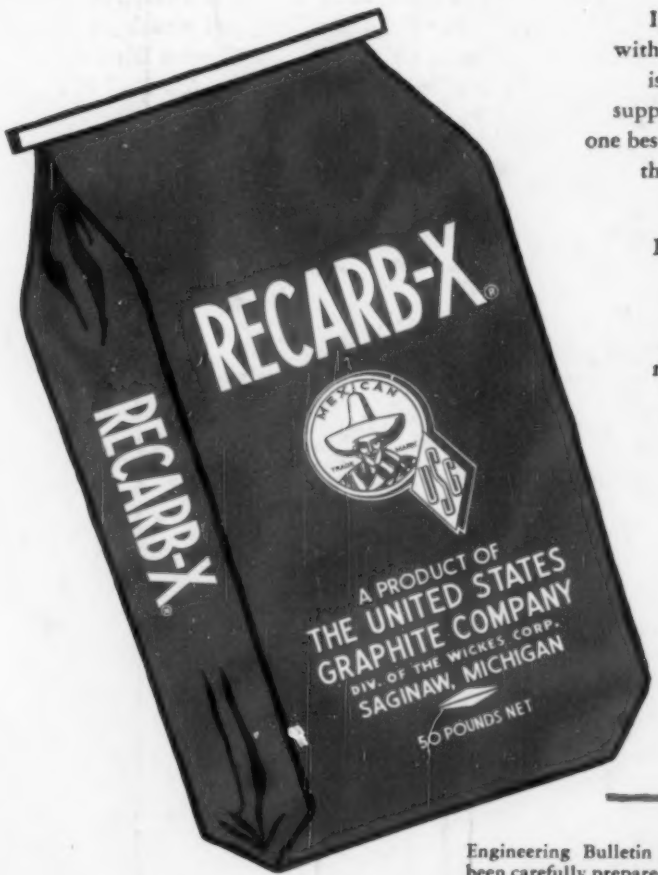

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Engineering Bulletin No. 11 has been carefully prepared to give you complete information on the use of RECARB-X in basic open hearth practices, acid open hearth practice and electric furnace operations. Write for Bulletin No. 11.

GS-251-1

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